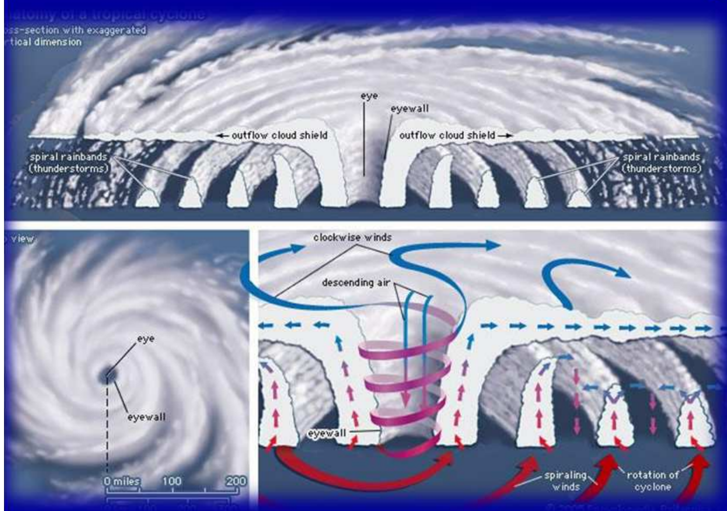
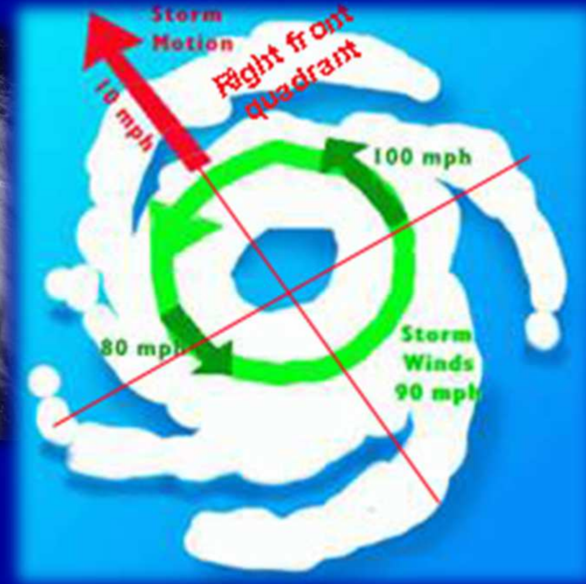
Hurricane Structure: Theory and Application





John Cangialosi

National Hurricane Center

World Meteorological Organization Workshop

Is this Tropical, Subtropical, or Extratropical?

Subtropical

Tropical

Extratropical

(a) Tropical
(b) Subtropical
(c) Extratropical

Is this Tropical, Subtropical, or Extratropical?

“Tropical Storm” Cindy

(a) Tropical
(b) Subtropical
(c) Extratropical

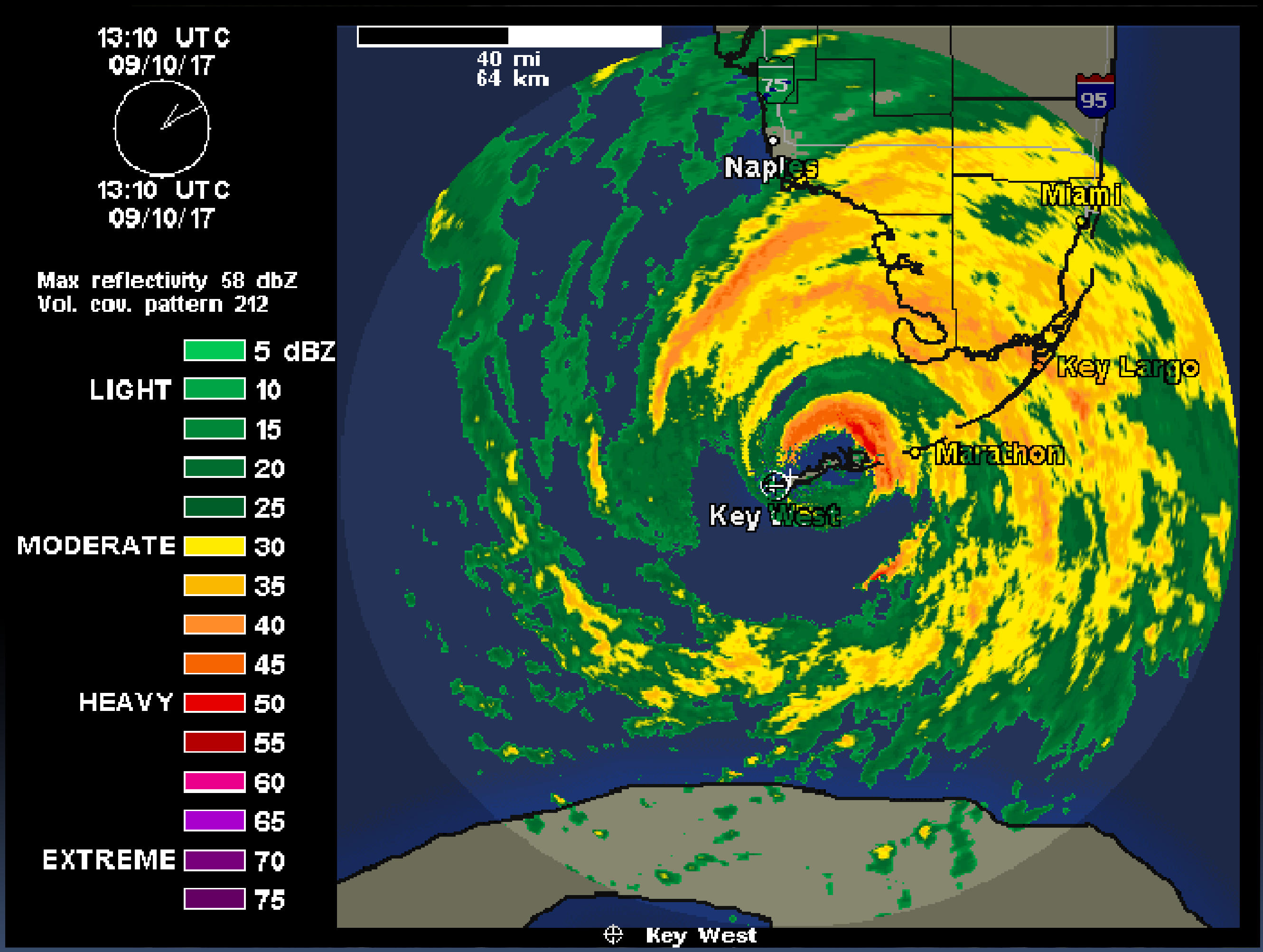
Outline for this presentation

* Background
* Application and Predictions
* Verification
* Exercise

Intensity and Structure Parameters that NHC analyzes and predicts

- Maximum Wind Speed
- Radius of 34-,50-,64-kt winds
- Minimum Pressure
- Radius of Maximum Wind
- Radius of the Outermost Closed Isobar

Hurricane Structure



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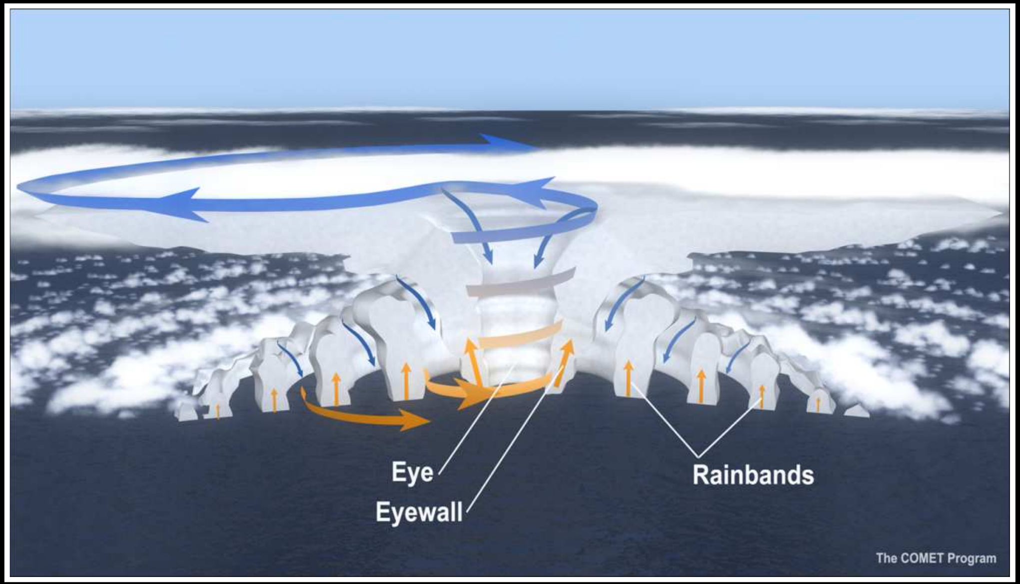
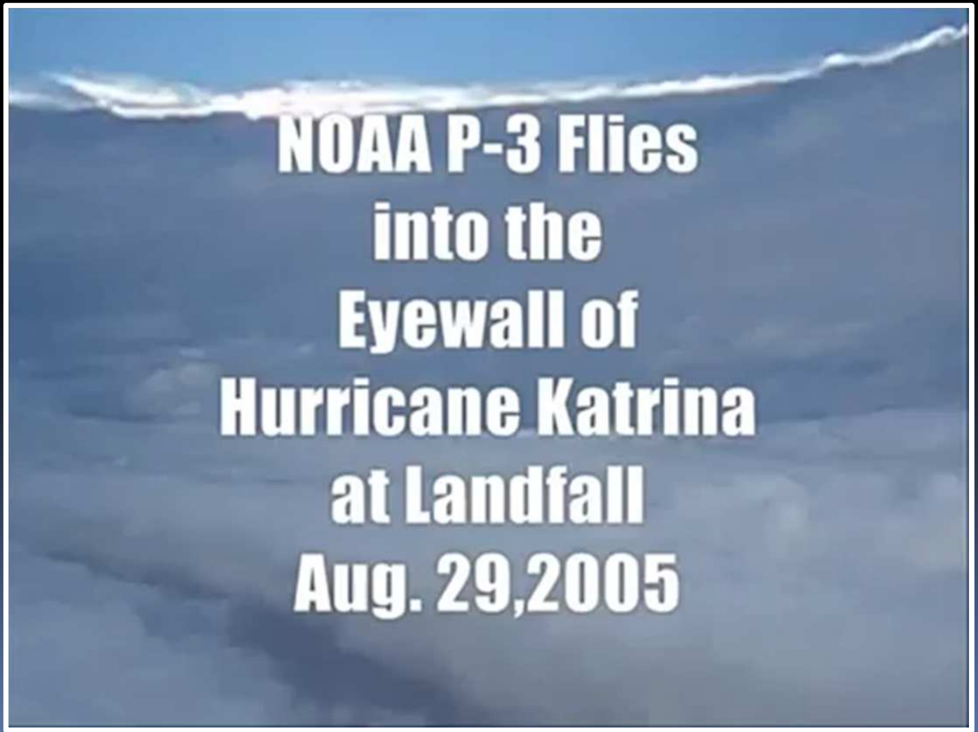
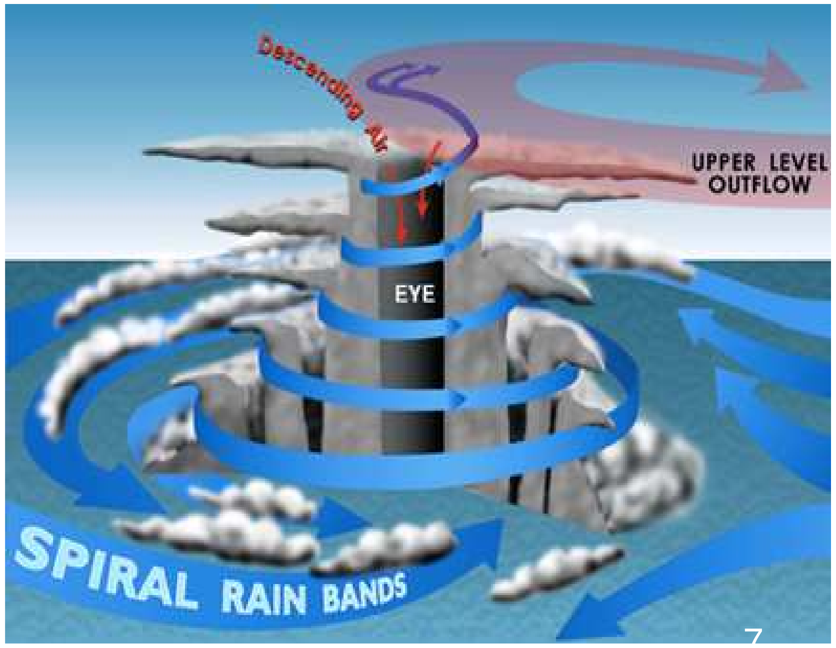
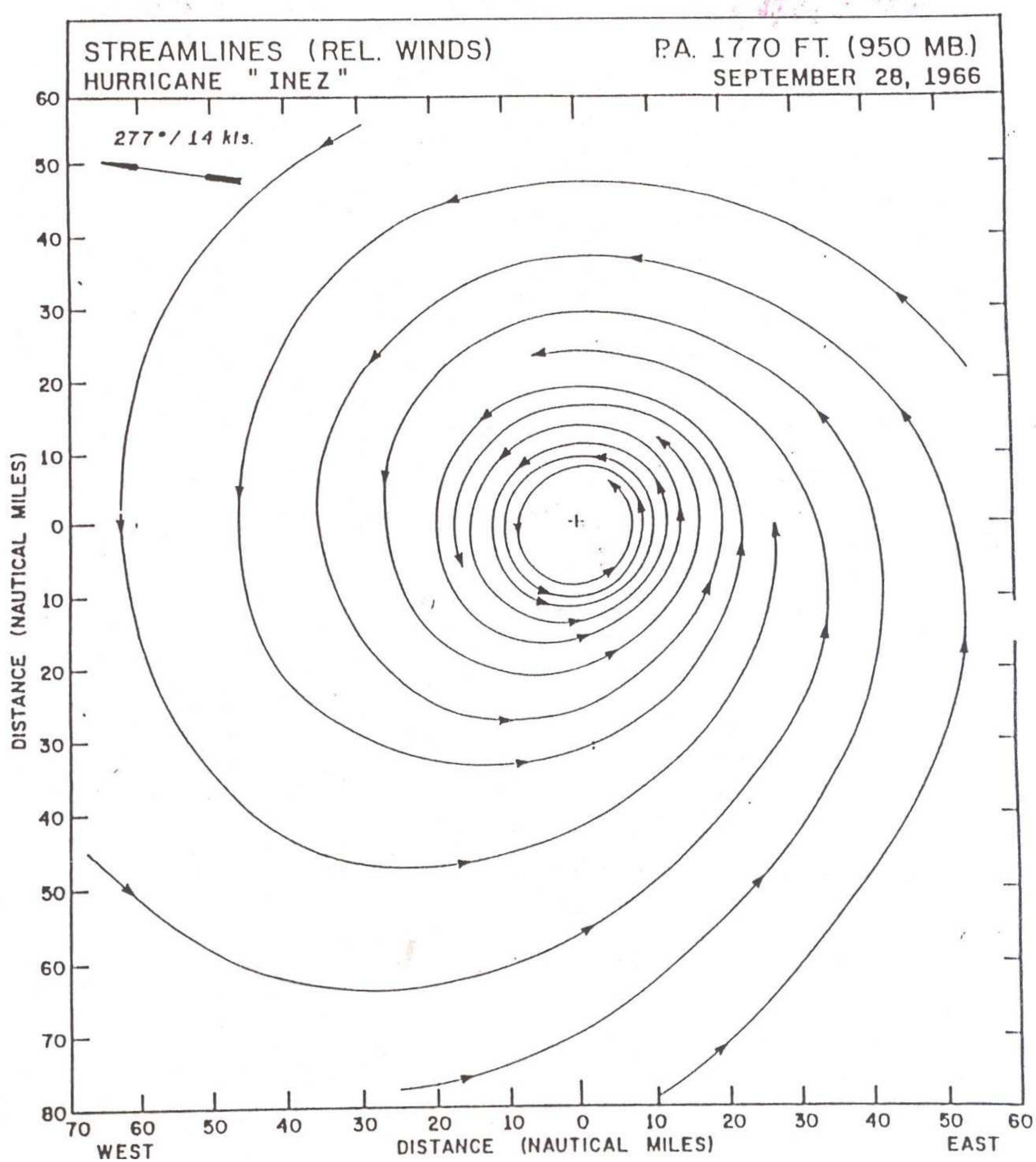
Structure of a Hurricane



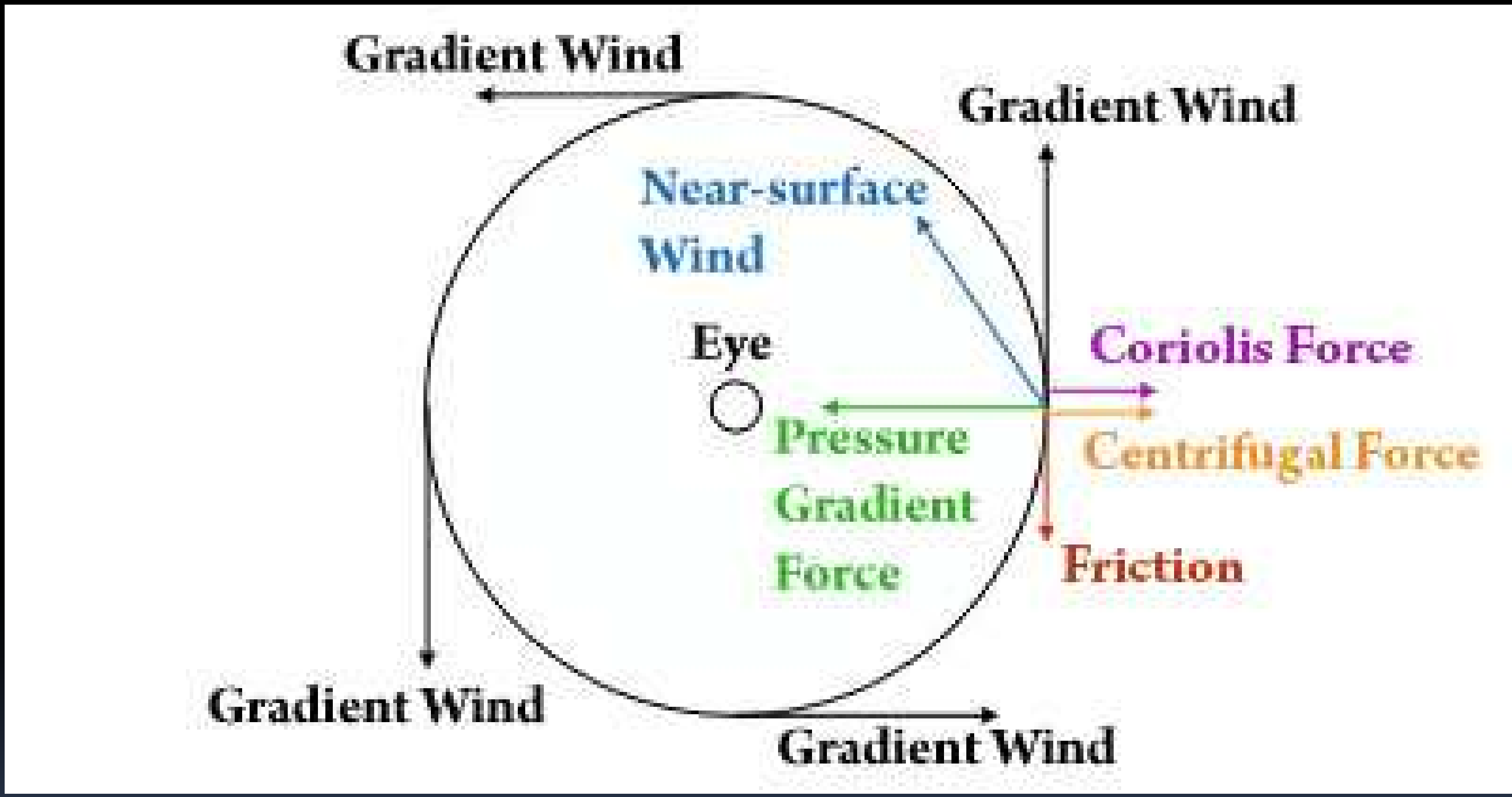






Notice the symmetric, inward spiraling flow.

Primary Circulation



Wind speeds are close to symmetric – only after subtracting the forward motion.

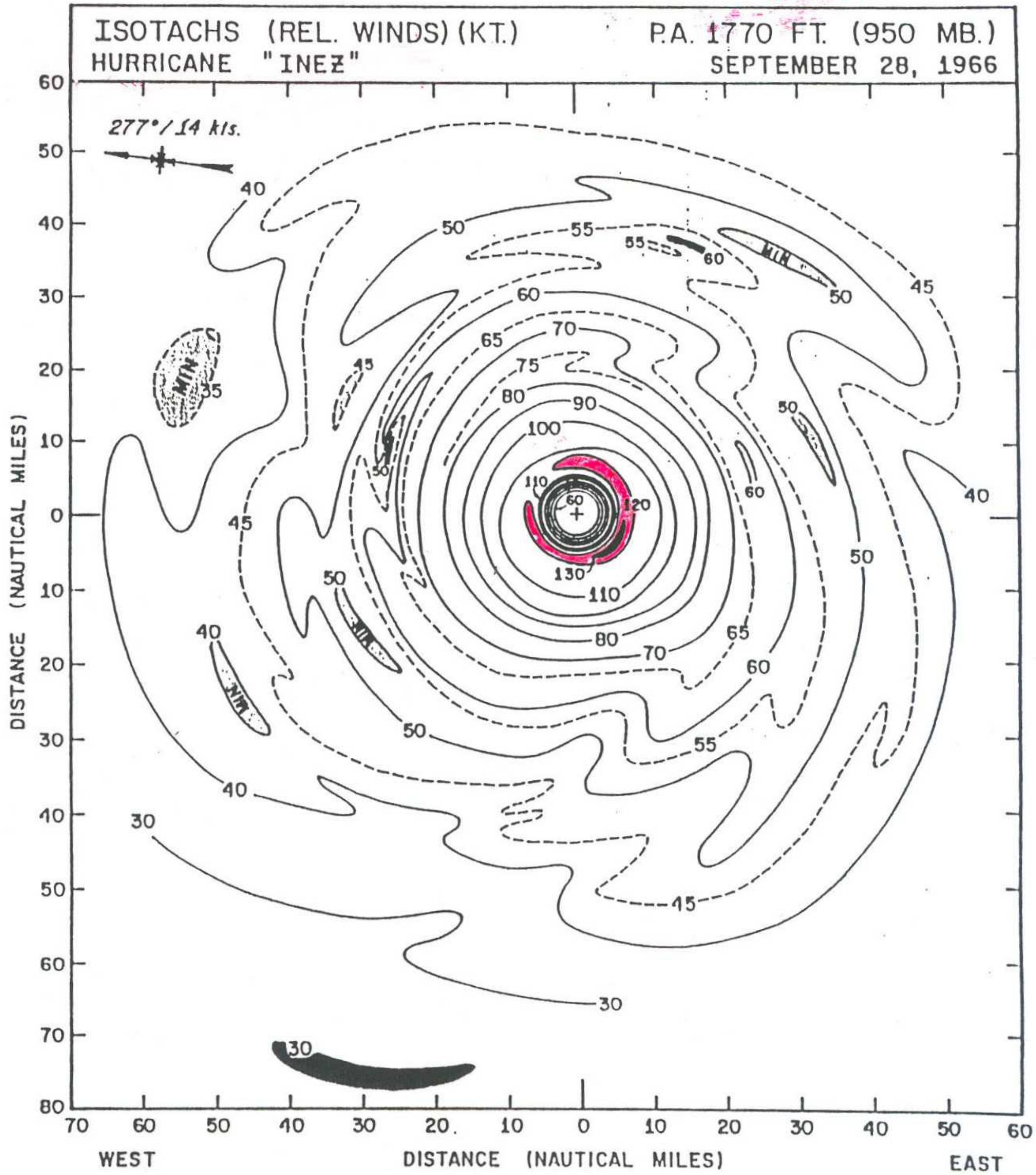
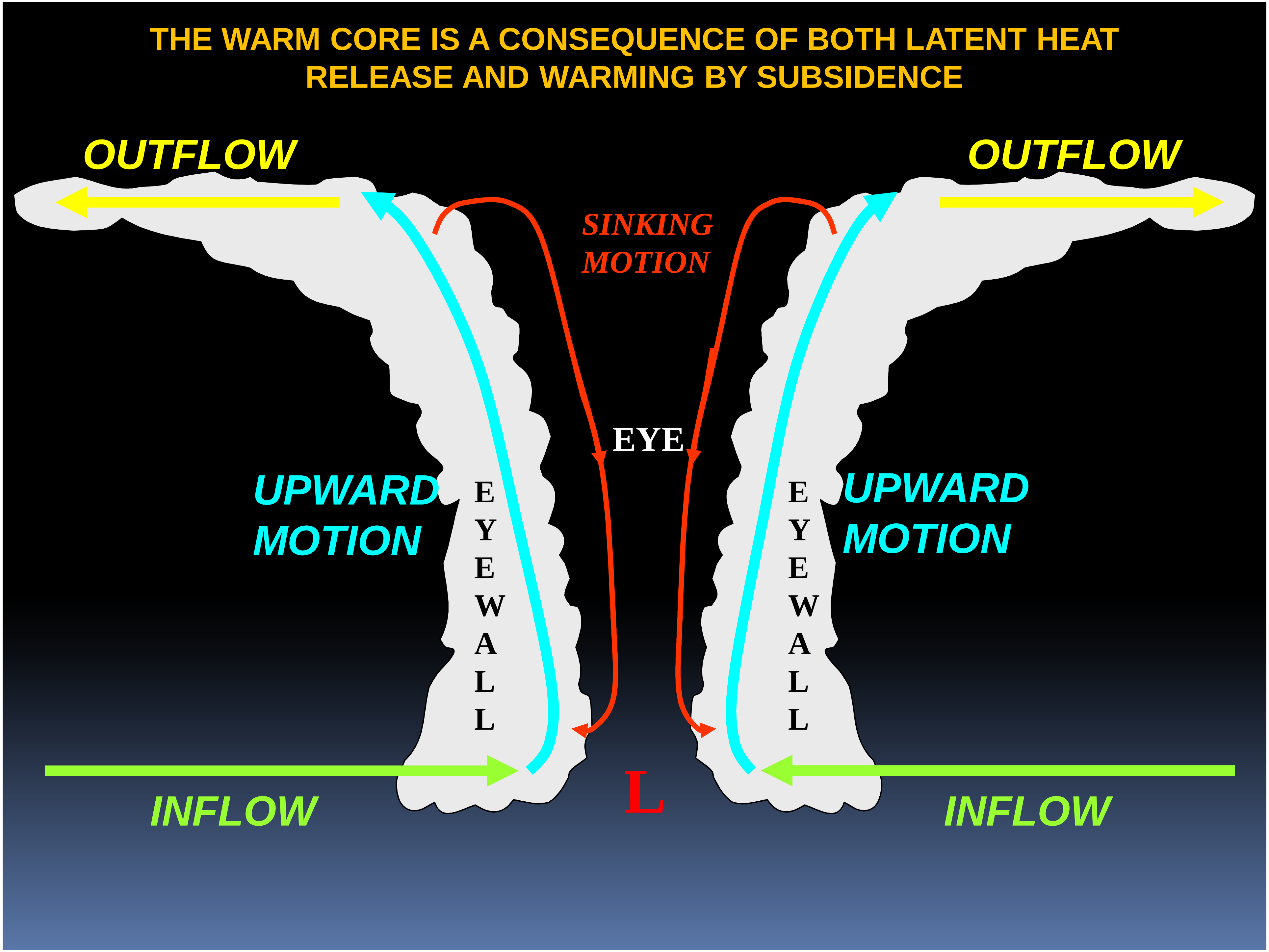
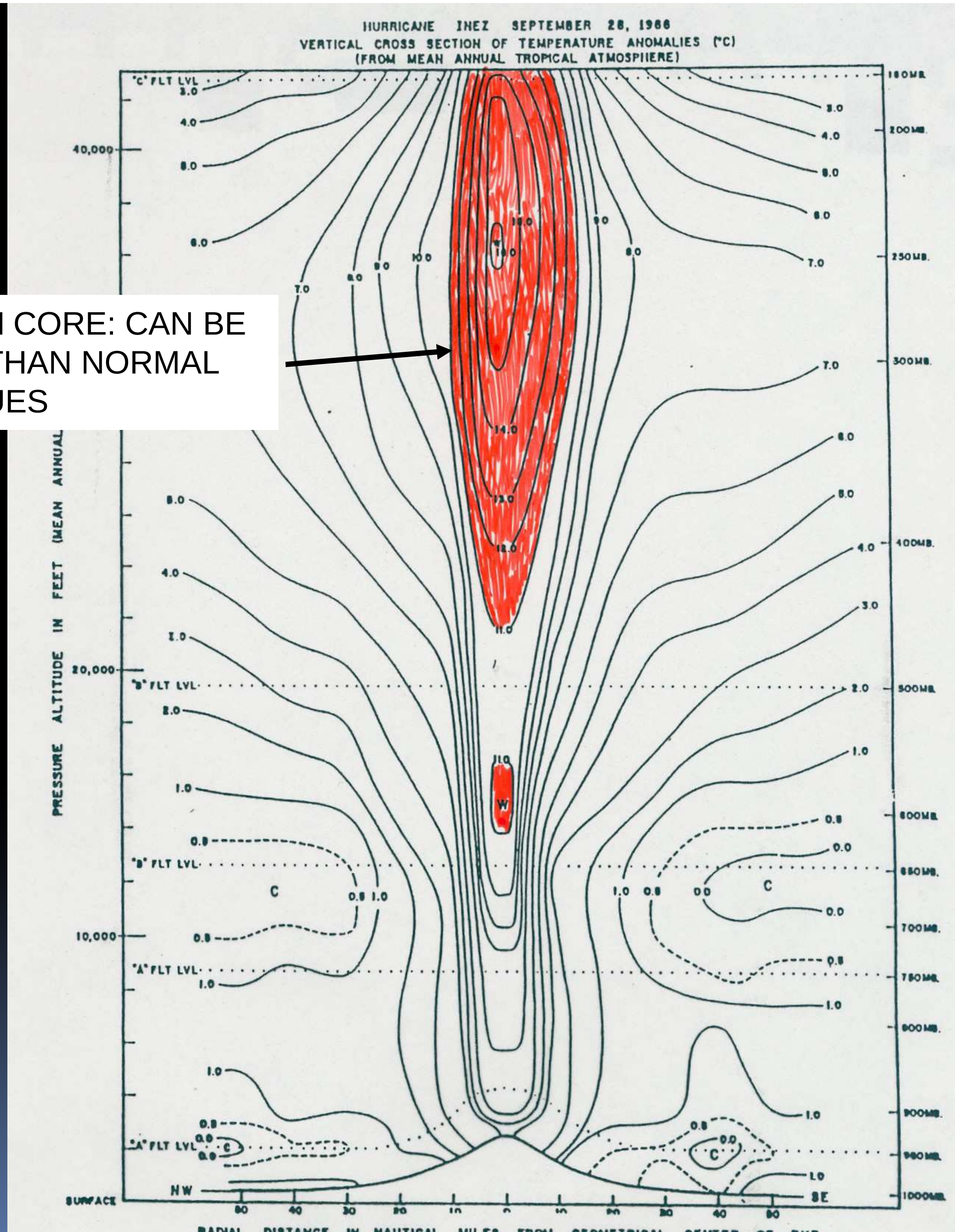


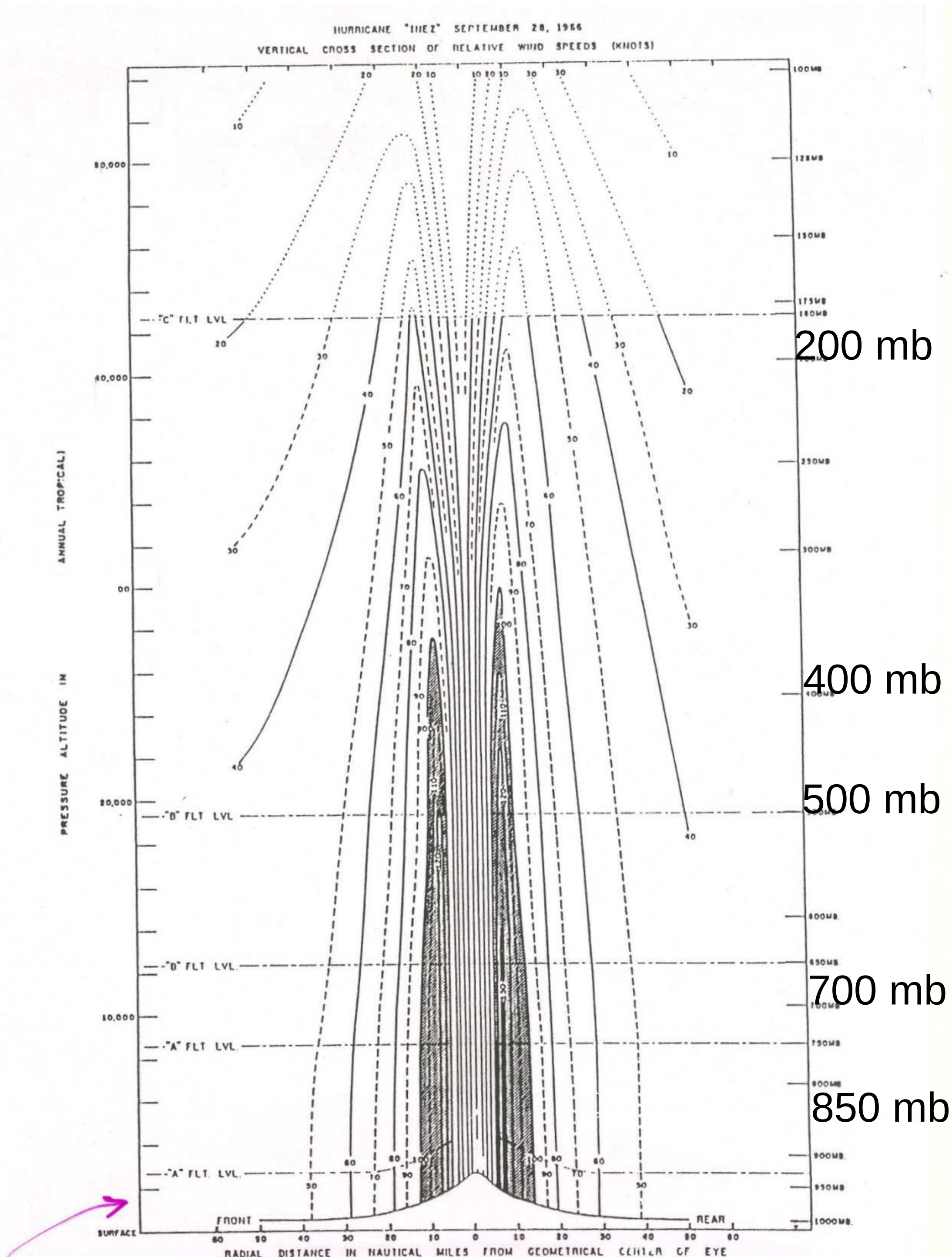
FIG. 2.4b. Low-level (950 mb) isotachs (kt) in Hurricane Inez (1966) (Hawkins and Imbembo, 1976).

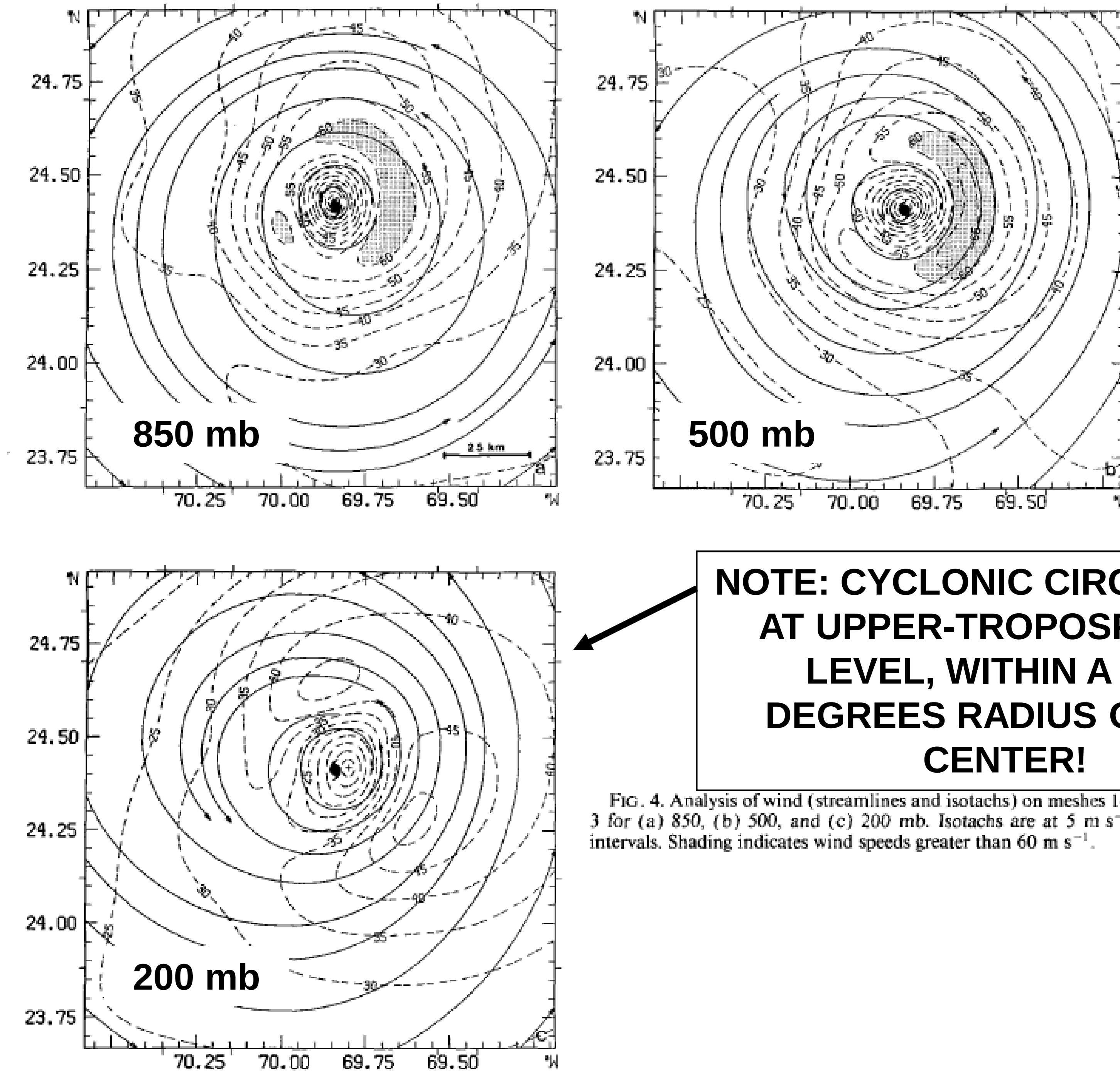

THE WARM CORE IS A CONSEQUENCE OF BOTH LATENT HEAT
RELEASE AND WARMING BY SUBSIDENCE
OUTFLOW
OUTFLOW
SINKING
MOTION
EYE
UPWARD
MOTION
EYEWALL
EYEWALL
UPWARD
MOTION
L
INFLOW
INFLOW

INTENSE WARM CORE: CAN BE 16 K WARMER THAN NORMAL TROPICAL VALUES



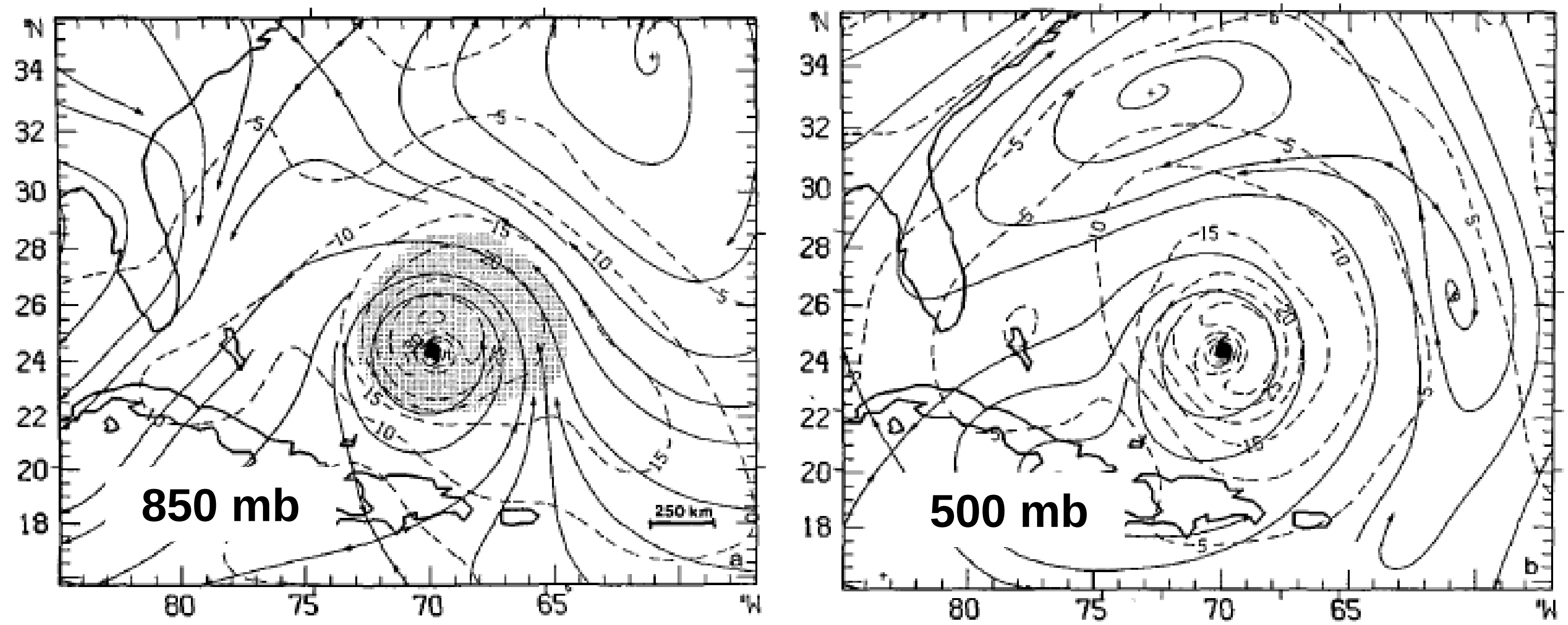
DEEP-LAYER CYCLONIC CIRCULATION

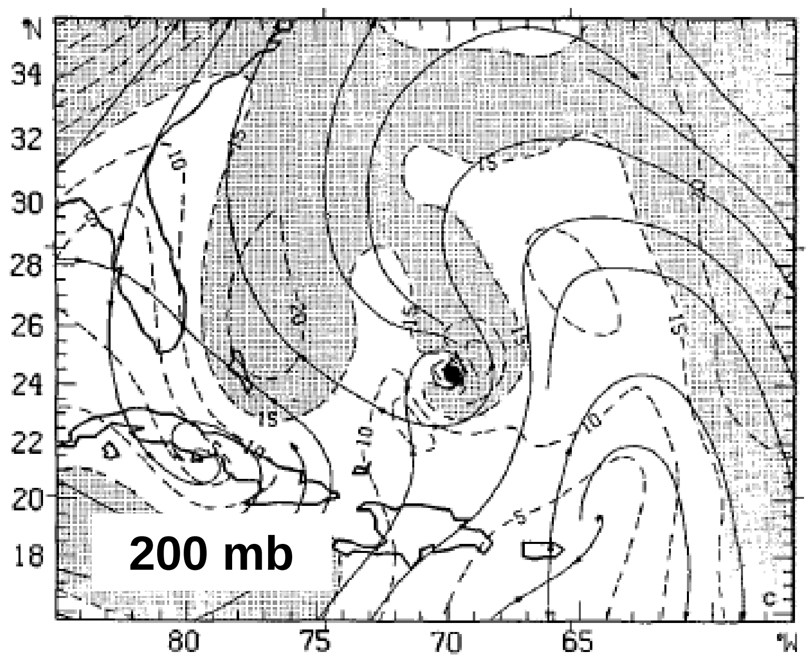




NOTE: CYCLONIC CIRCULATION AT UPPER-TROPOSPHERIC LEVEL, WITHIN A FEW DEGREES RADIUS OF THE CENTER!

FIG. 4. Analysis of wind (streamlines and isotachs) on meshes 1–3 for (a) 850, (b) 500, and (c) 200 mb. Isotachs are at 5 m s^{-1} intervals. Shading indicates wind speeds greater than 60 m s^{-1}.



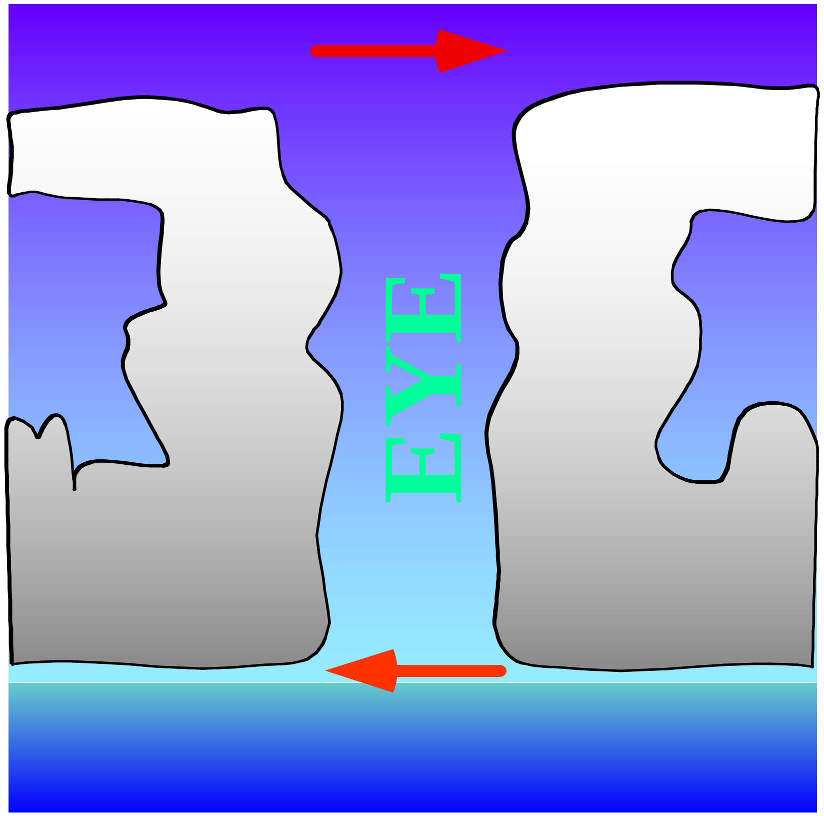


BEYOND A FEW DEGREES RADIUS FROM THE CENTER, THE UPPER-TROPOSPHERIC FLOW TURNS ANTICYCLONIC

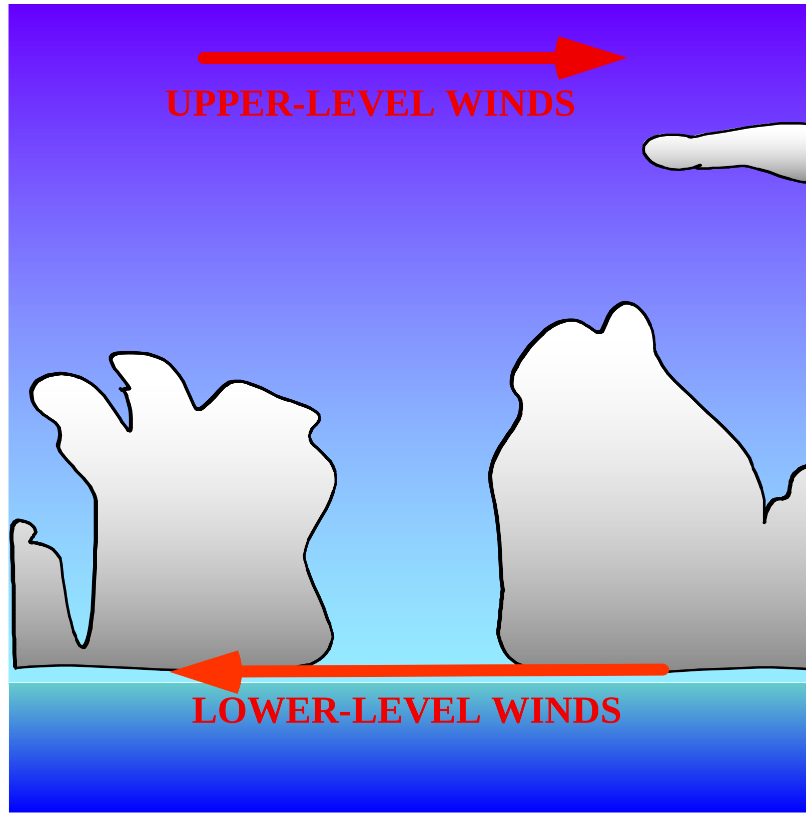
FIG. 5. Analysis of wind (streamlines and isotachs) for meshes 6–7 for (a) 850, (b) 500, and (c) 200 mb. Isotachs are at 5 m s^{-1} intervals. Shading in (a) indicates area of tropical storm force winds (17.5 m s^{-1}), and in (c) areas with winds greater than 15 m s^{-1}.

The Effects of Wind Shear

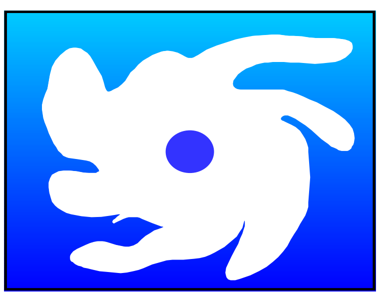
Effects of Vertical Wind Shear (V_z) on Tropical Cyclones

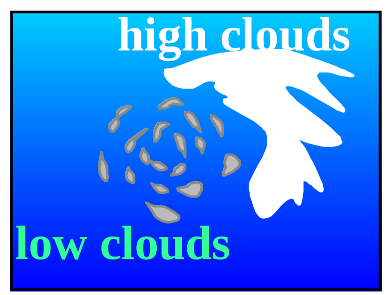


WEAK SHEAR = FAVORABLE



STRONG SHEAR = *UN*FAVORABLE





Neal Dorst/Stan Goldenberg
Hurricane Research Division
AOML/NOAA
HRD

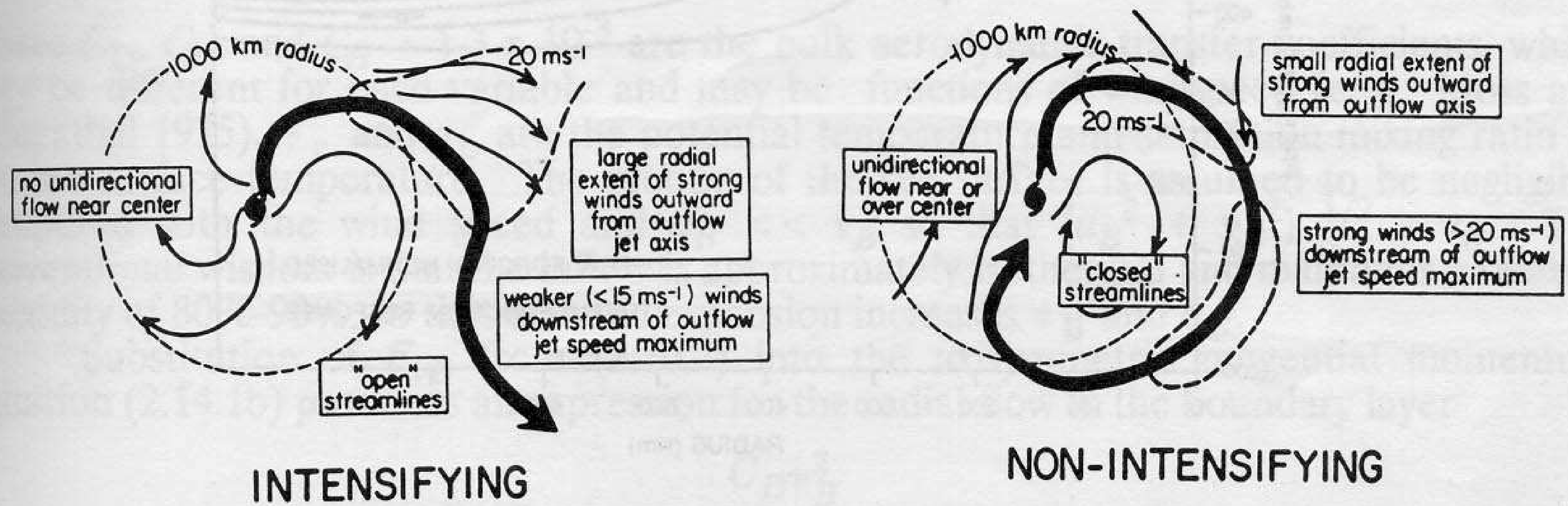
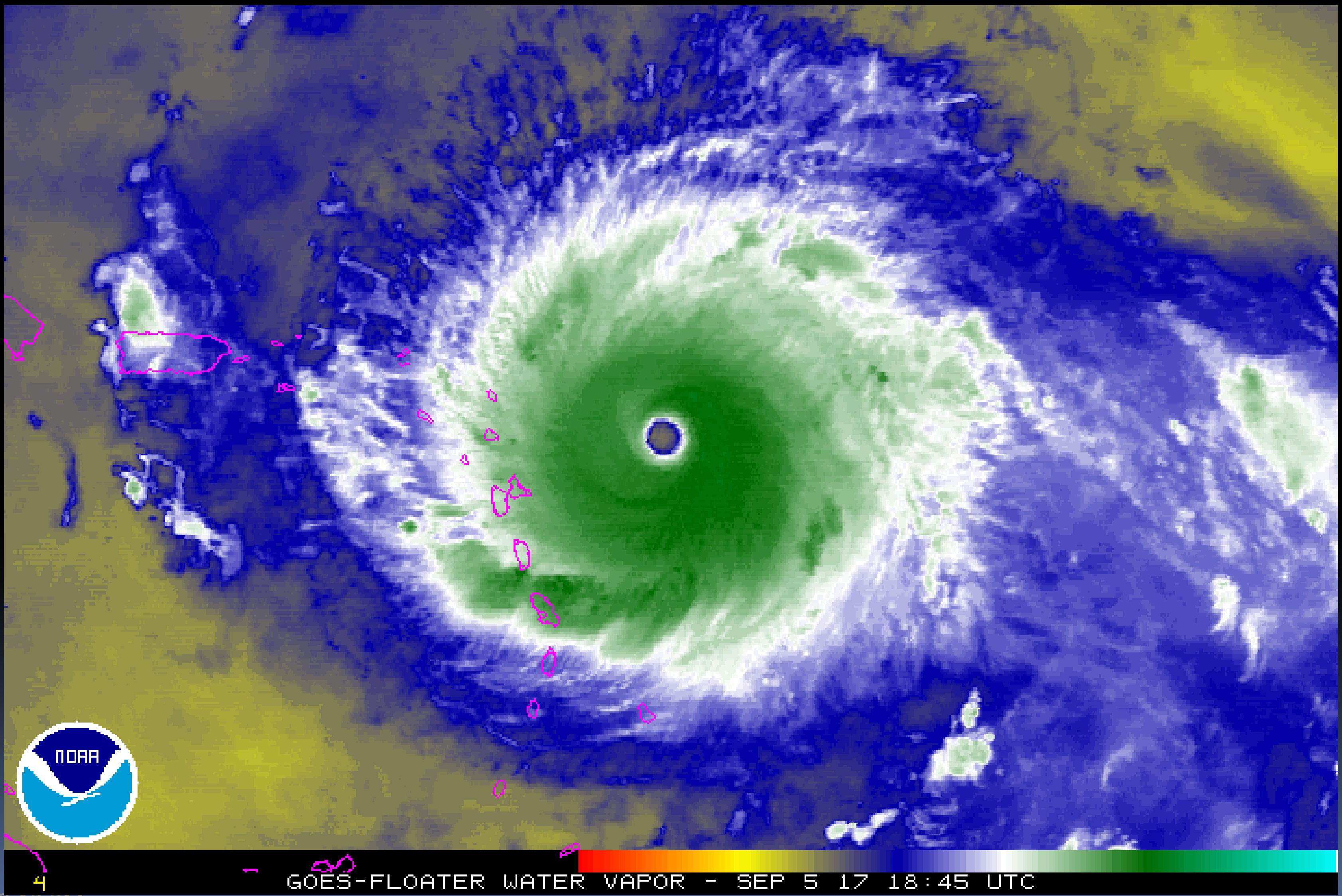


Fig. 2.17 Differences between the outflow and upper-level asymmetries of intensifying and nonintensifying hurricanes (Merrill 1988b).

Well-established outflow



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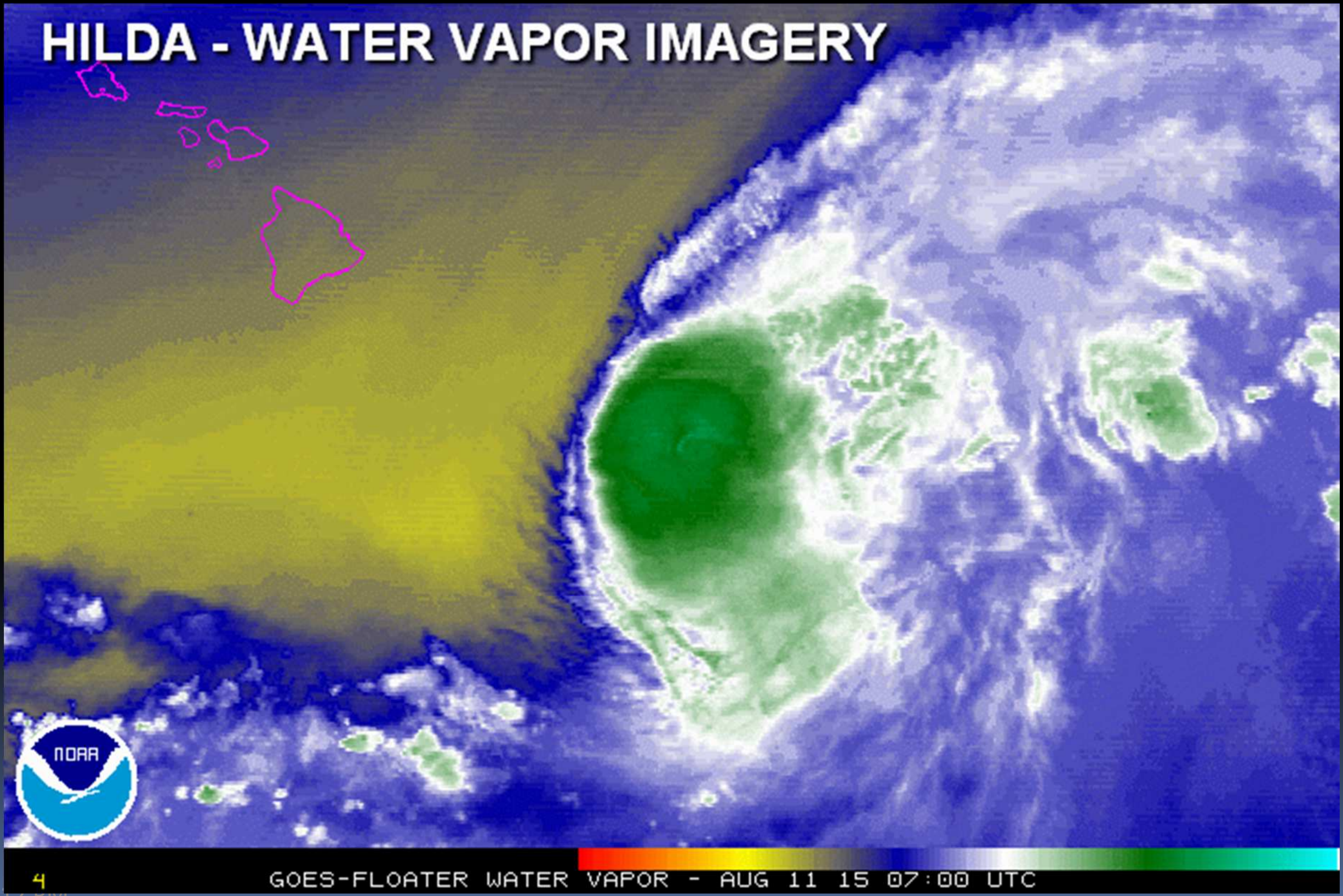
Restricted outflow



Intensifying vs. Non-Intensifying

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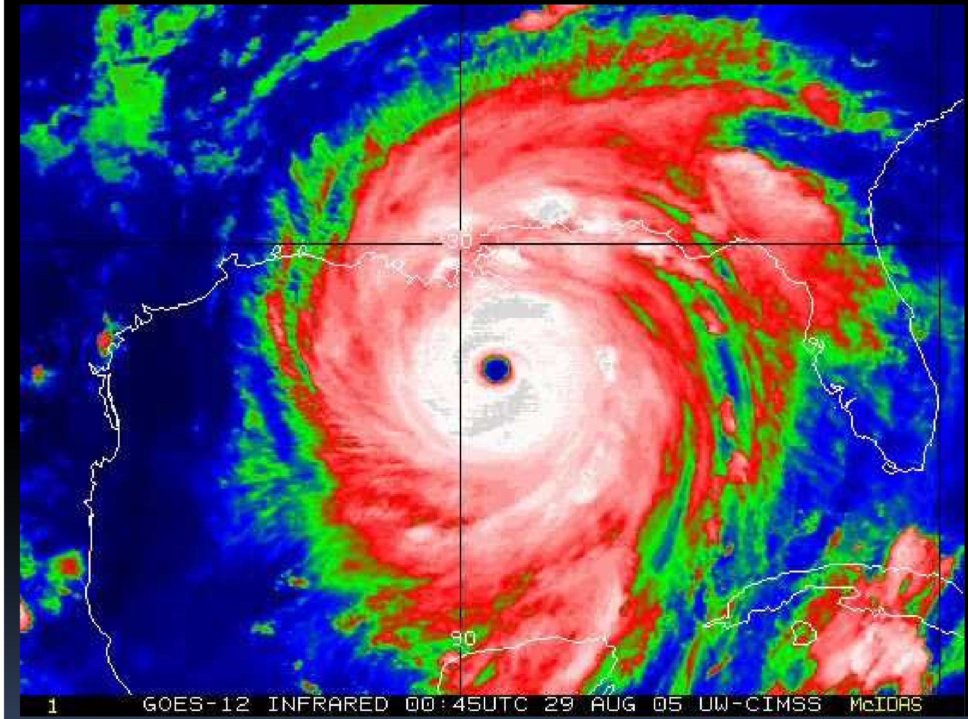
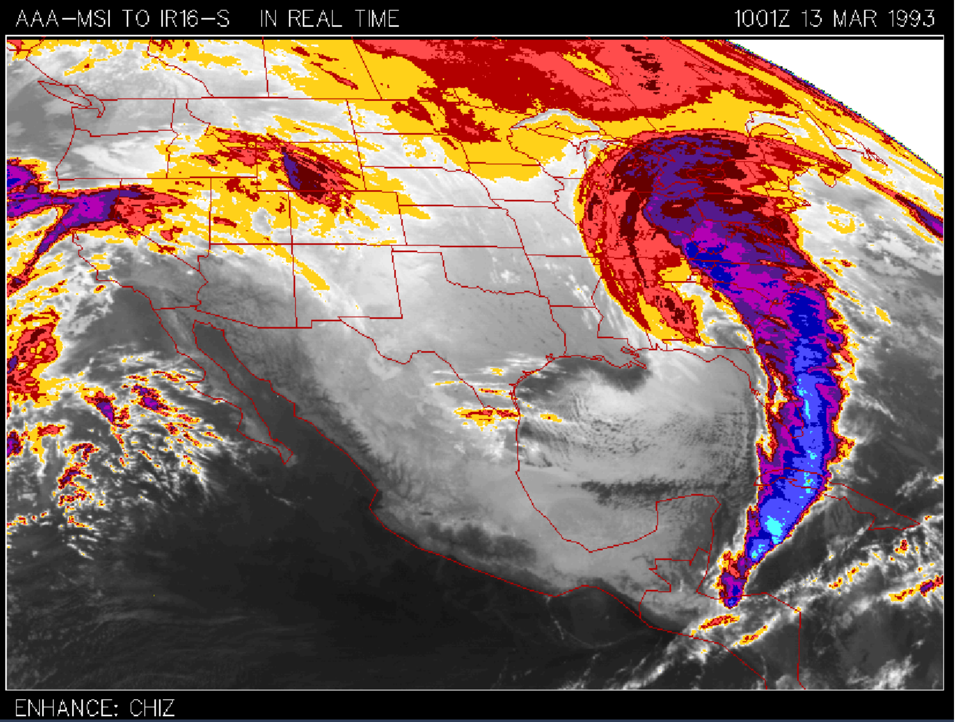
The Extremes:
Tropical vs. Extratropical Cyclones

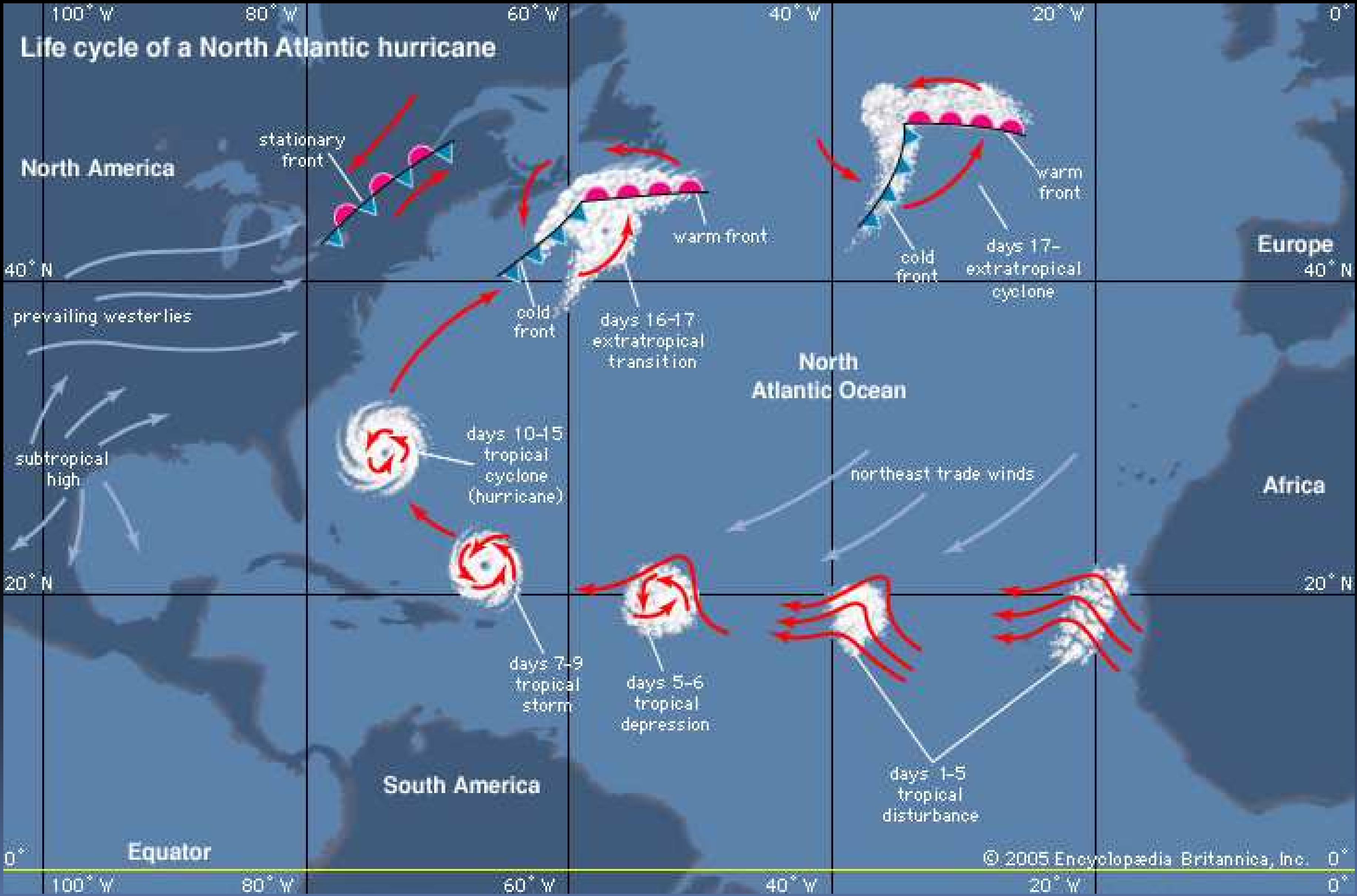


Hurricane Katrina (2005)

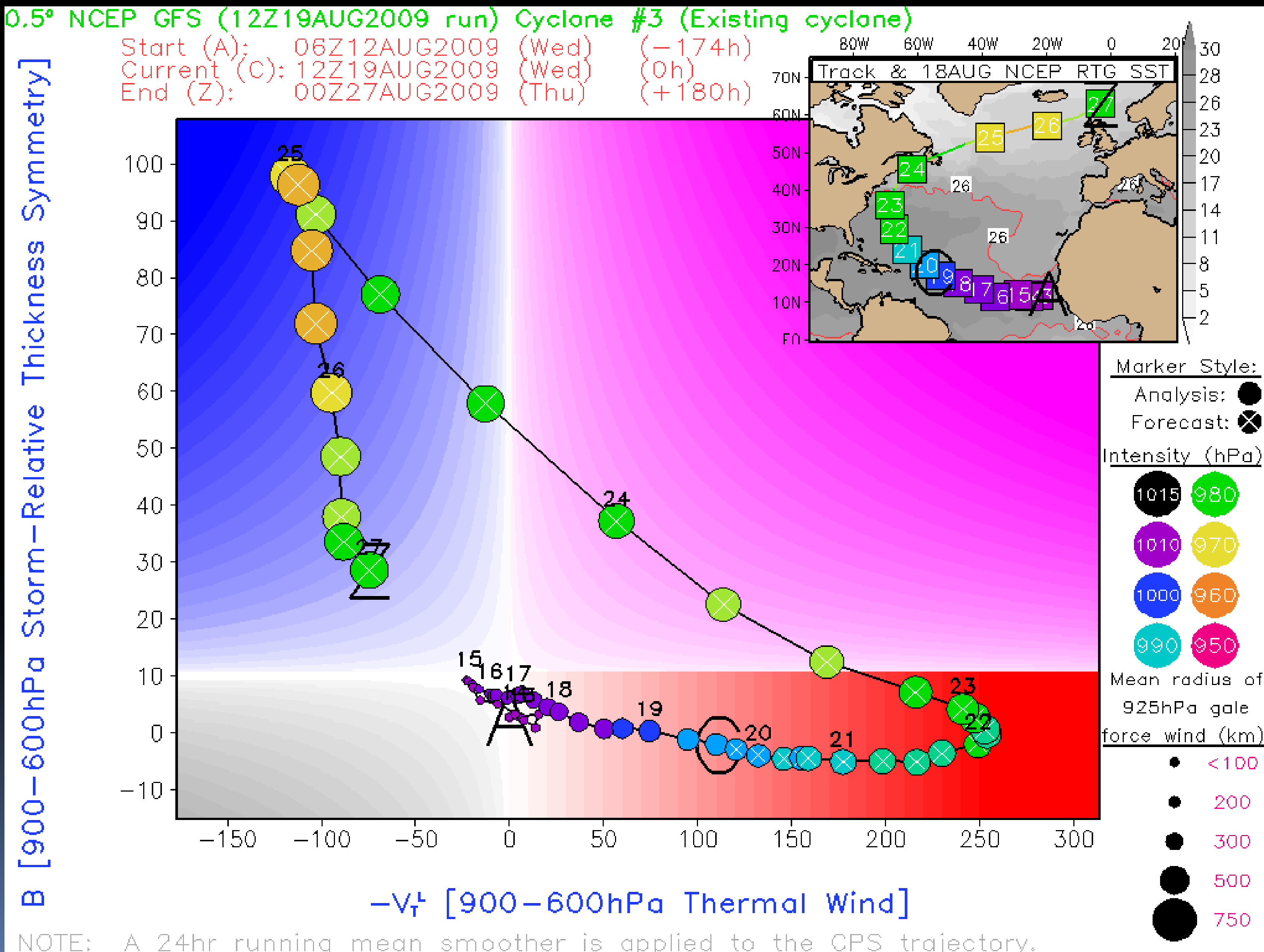


Superstorm Blizzard of March 1993

Life Cycle of a Cape Verde Hurricane



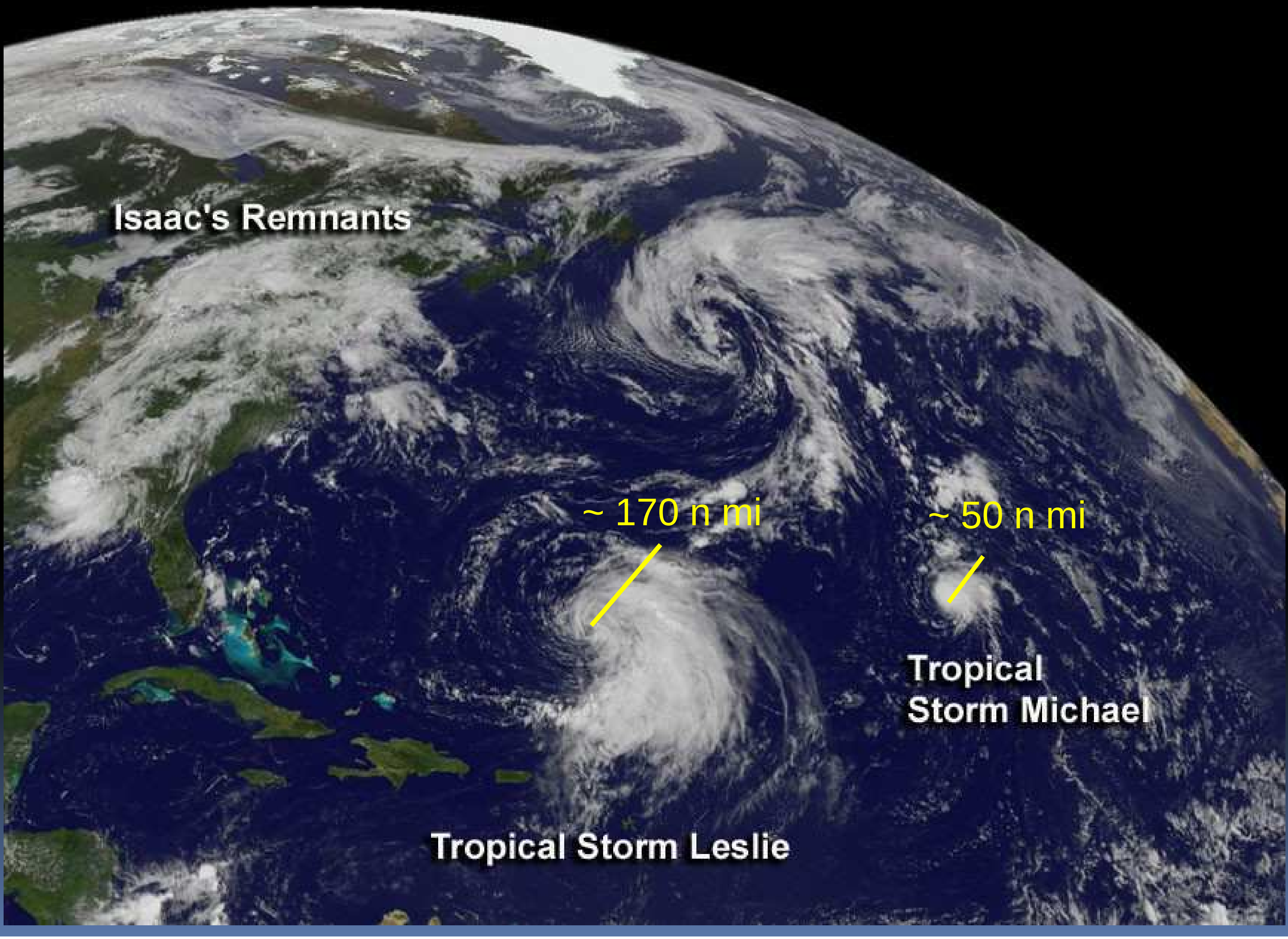
Cyclone Phase Space for Bill



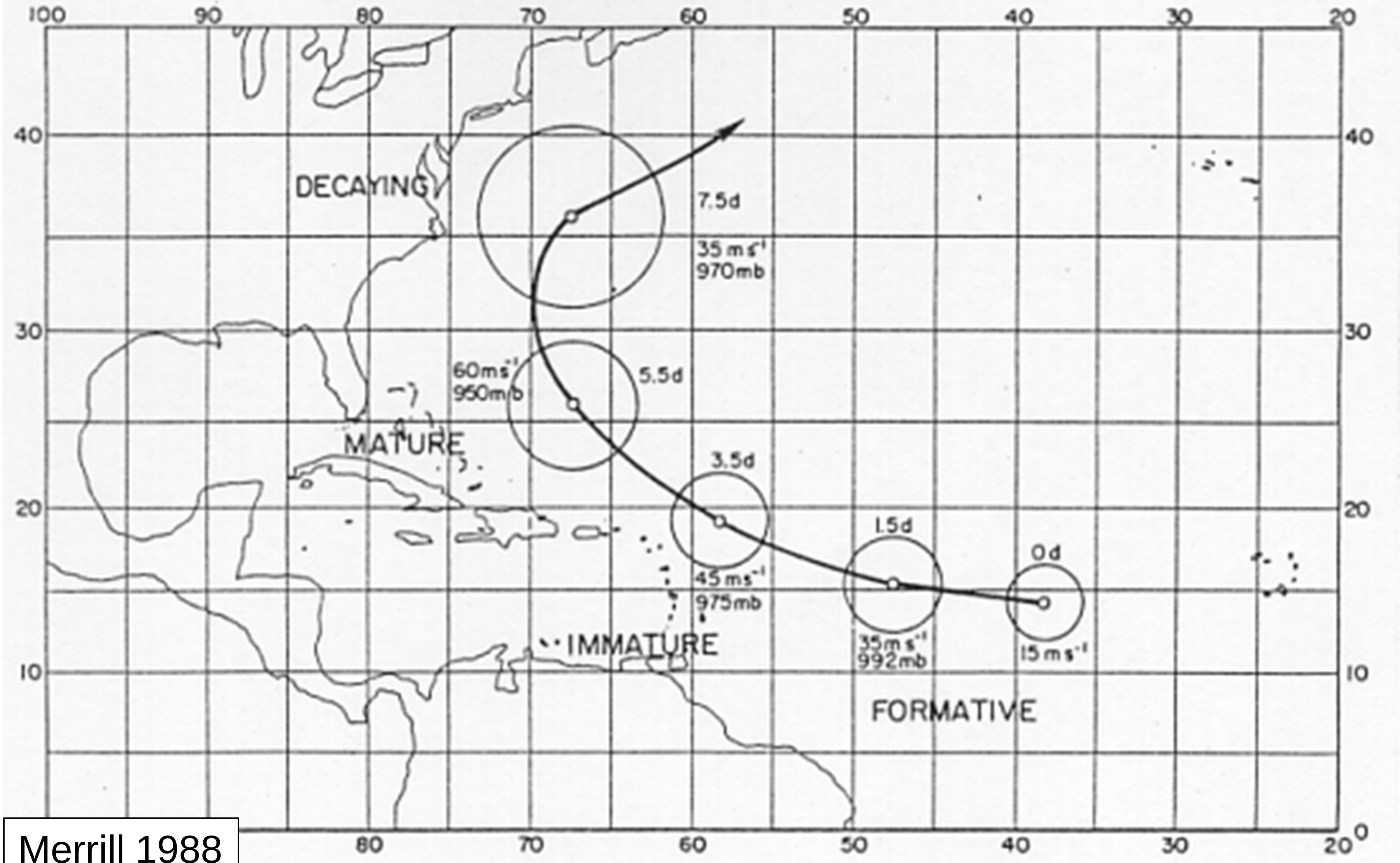
Hurricane Size Variability

Size Matters!

The Extremes: Tip vs. Tracy

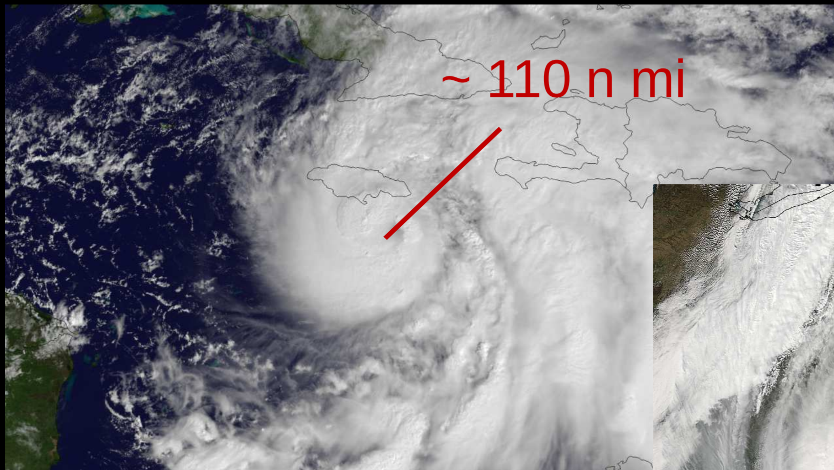

Isaac's Remnants
~ 170 n mi
~ 50 n mi
Tropical
Storm Michael
Tropical Storm Leslie

Tropical Cyclone Size Lifecycle

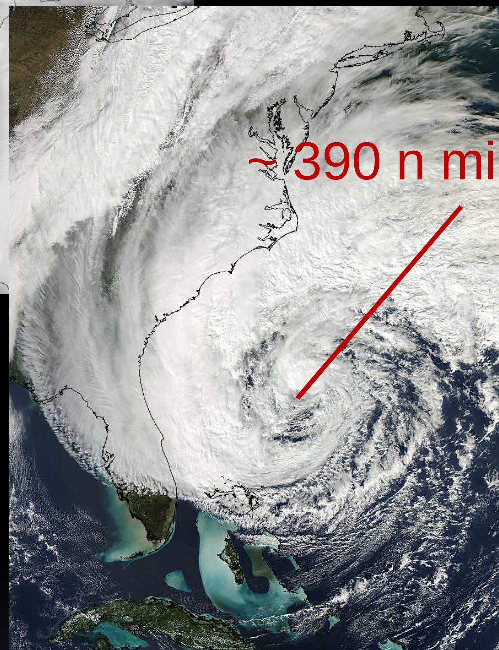


Merrill 1988

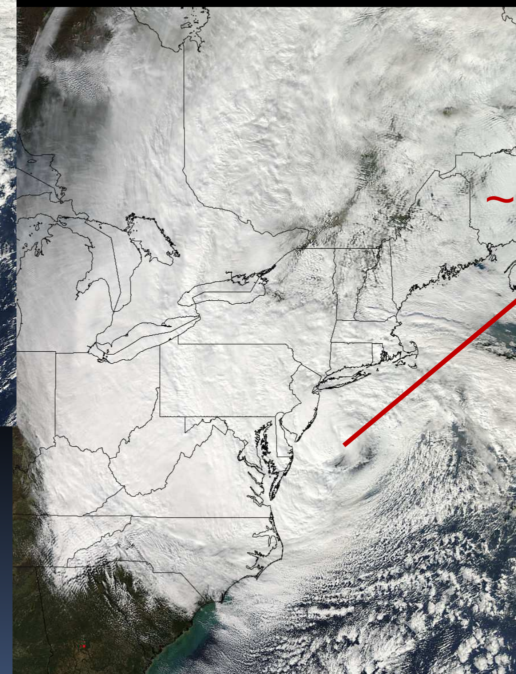
Hurricane Sandy



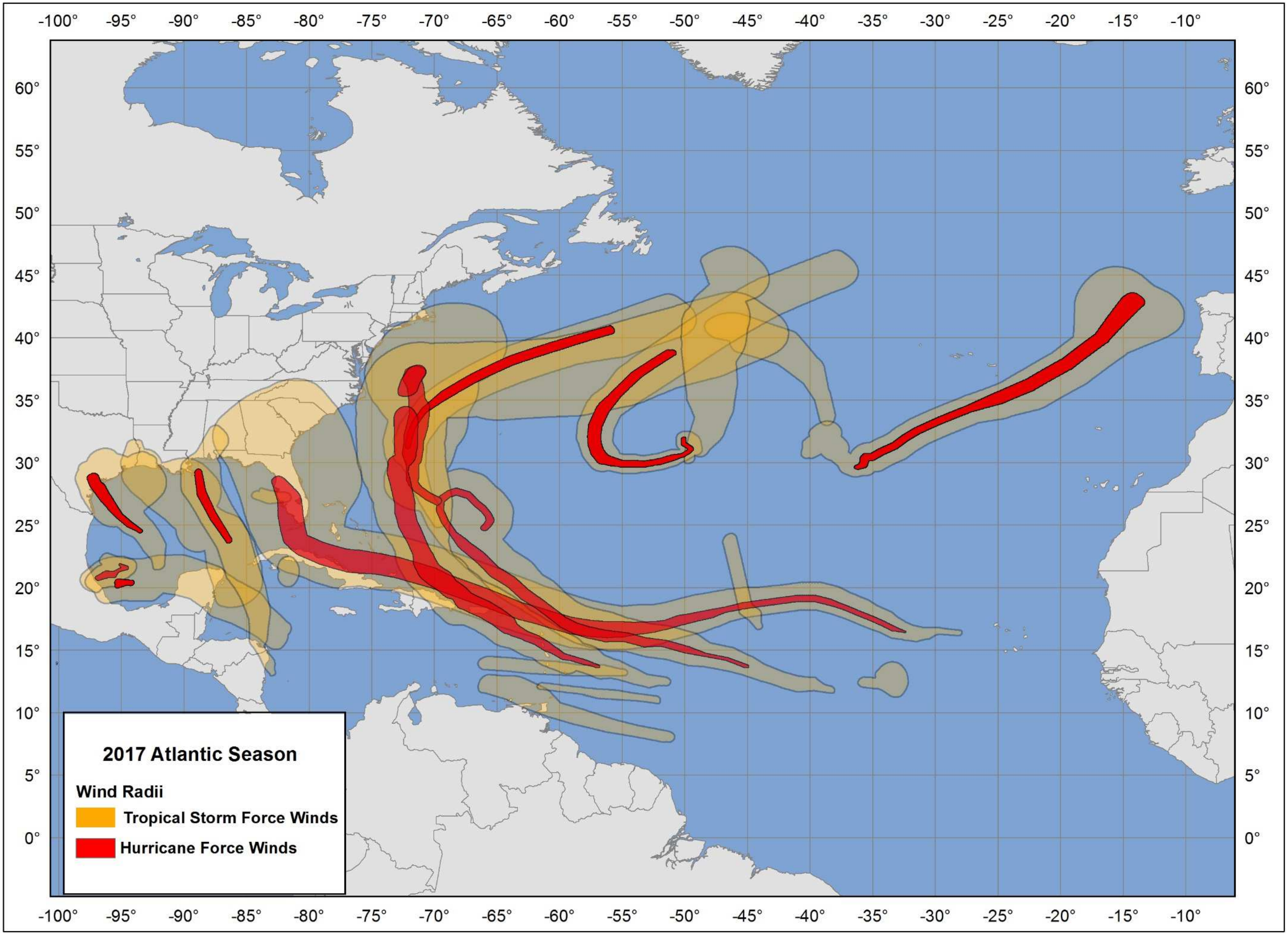
75 kt, 971 mb



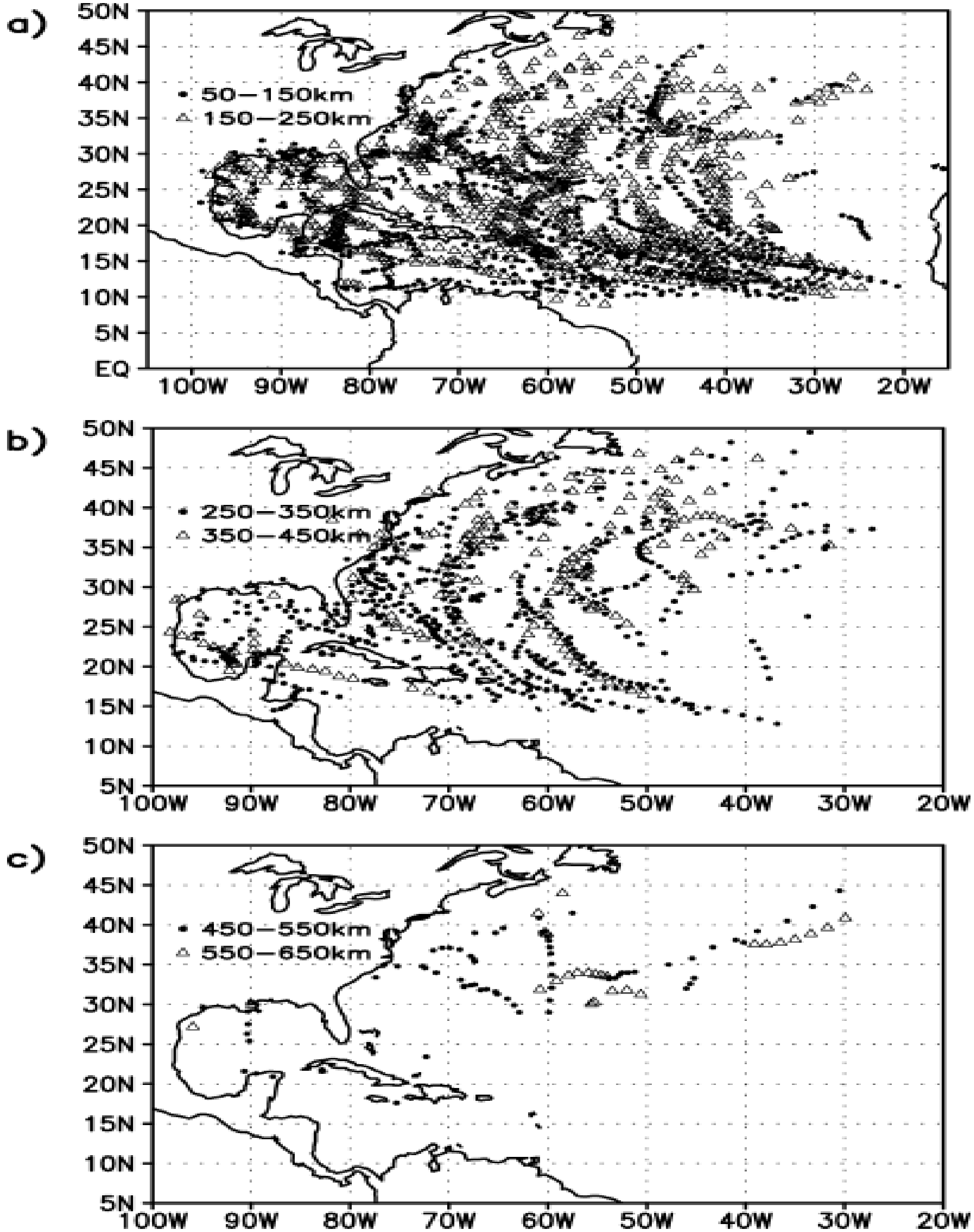
70 kt, 956 mb



75 kt, 943 mb

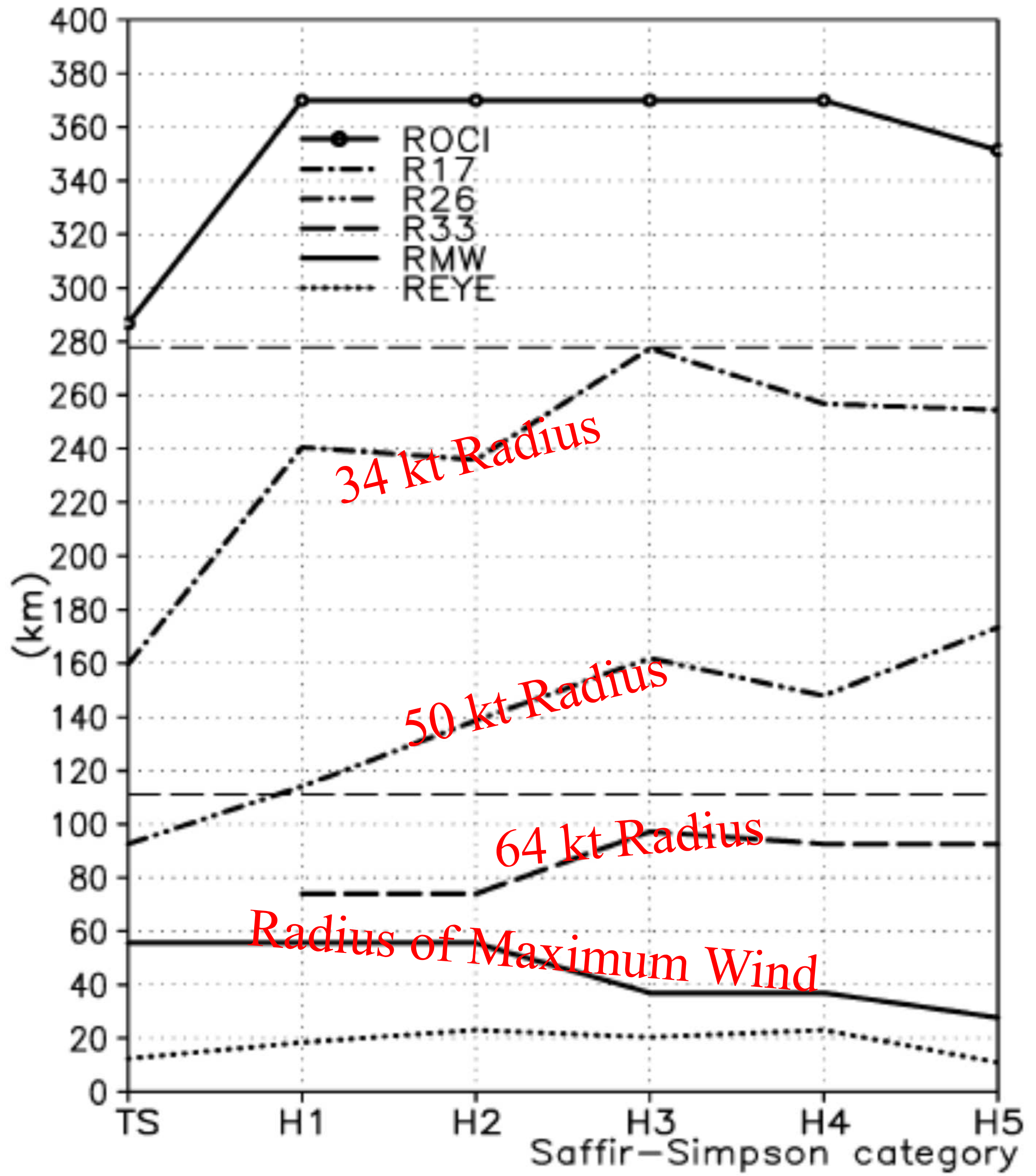


-100°
-95°
-90°
-85°
-80°
-75°
-70°
-65°
-60°
-55°
-50°
-45°
-40°
-35°
-30°
-25°
-20°
-15°
-10°
60°
55°
50°
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°
2017 Atlantic Season
Wind Radii
Tropical Storm Force Winds
Hurricane Force Winds



Radius of Tropical Storm Force Winds versus Location

Kimball and Mulekar (2004)



Size versus Intensity

Kimball and Mulekar (2004)

Pressure-Wind Relationship

$$\varphi < 18^o,$$

$$\Delta P = 5.962 - 0.267 V_{srm} - \left[\frac{V_{srm}}{18.26}\right]^2 - 6.8S$$

$$\varphi \geq 18^o$$

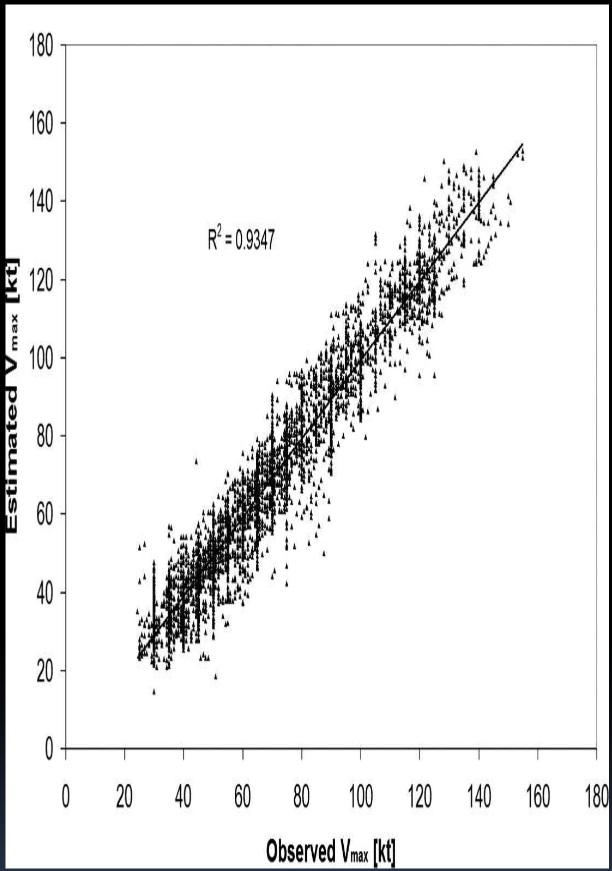
$$\Delta P = 23.286 - 0.483 V_{srm} - \left[\frac{V_{srm}}{24.254}\right]^2 - 12.587S - 0.483\varphi$$

Knaff, Zehr, and Courtney (2009)

Pressure-Wind Relationship

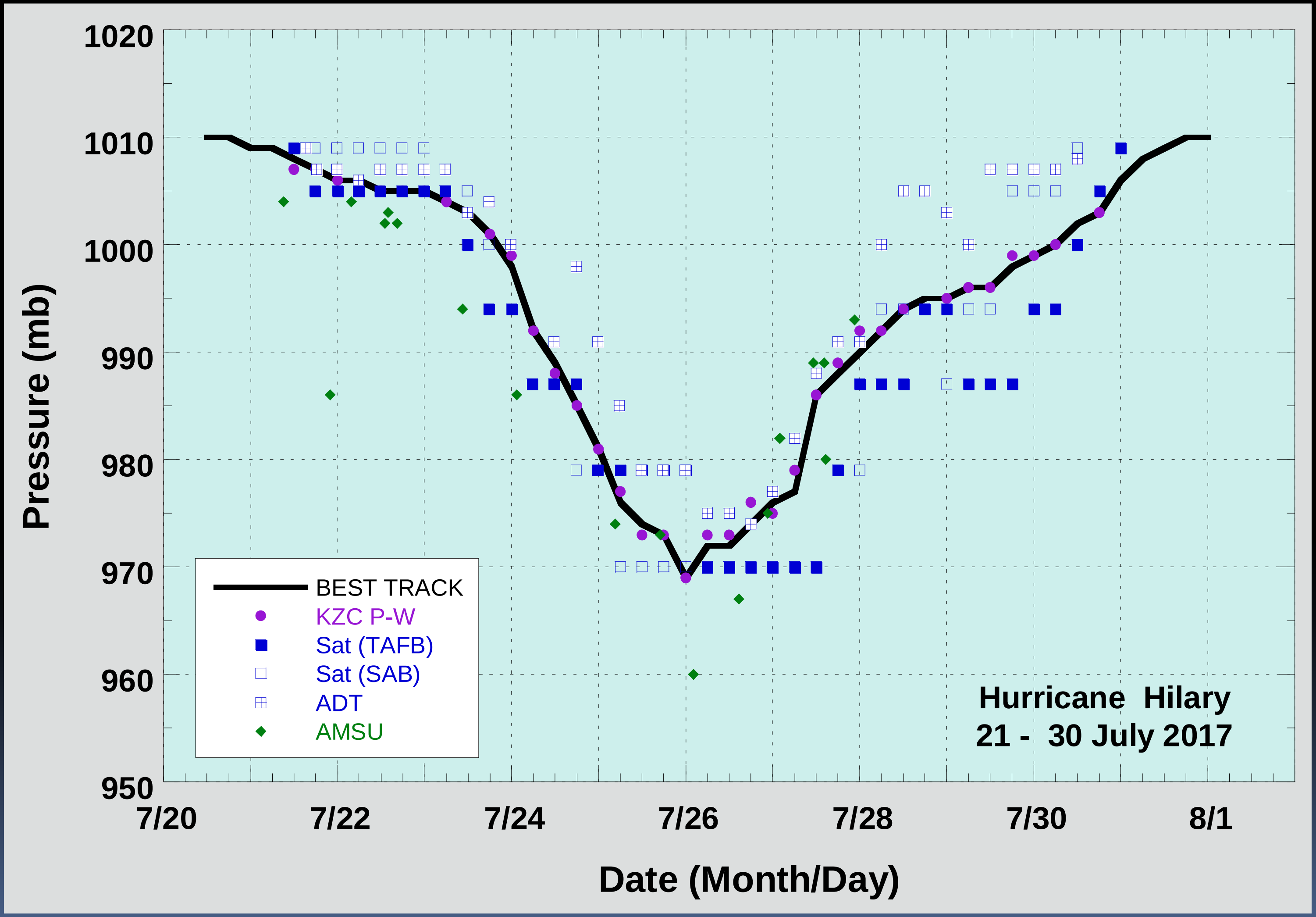
Knaff-Zehr-Courtney technique accounts for the following:

* Maximum wind speed
* 34-kt wind radii
* Latitude
* Environmental Pressure
* Forward Speed

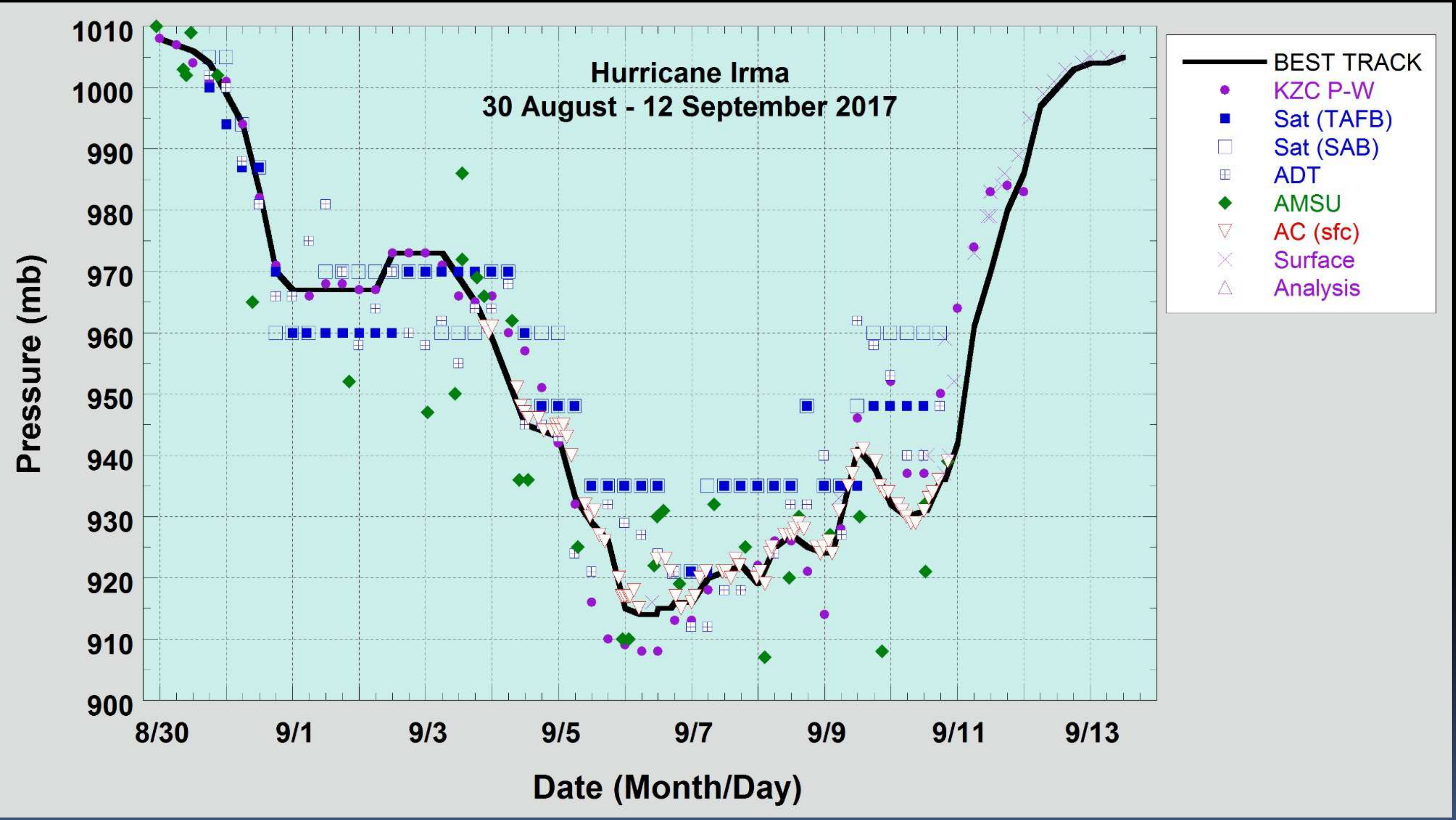


Knaff and Zehr (2007)

Sometimes we stick with it…



And sometimes we don't…



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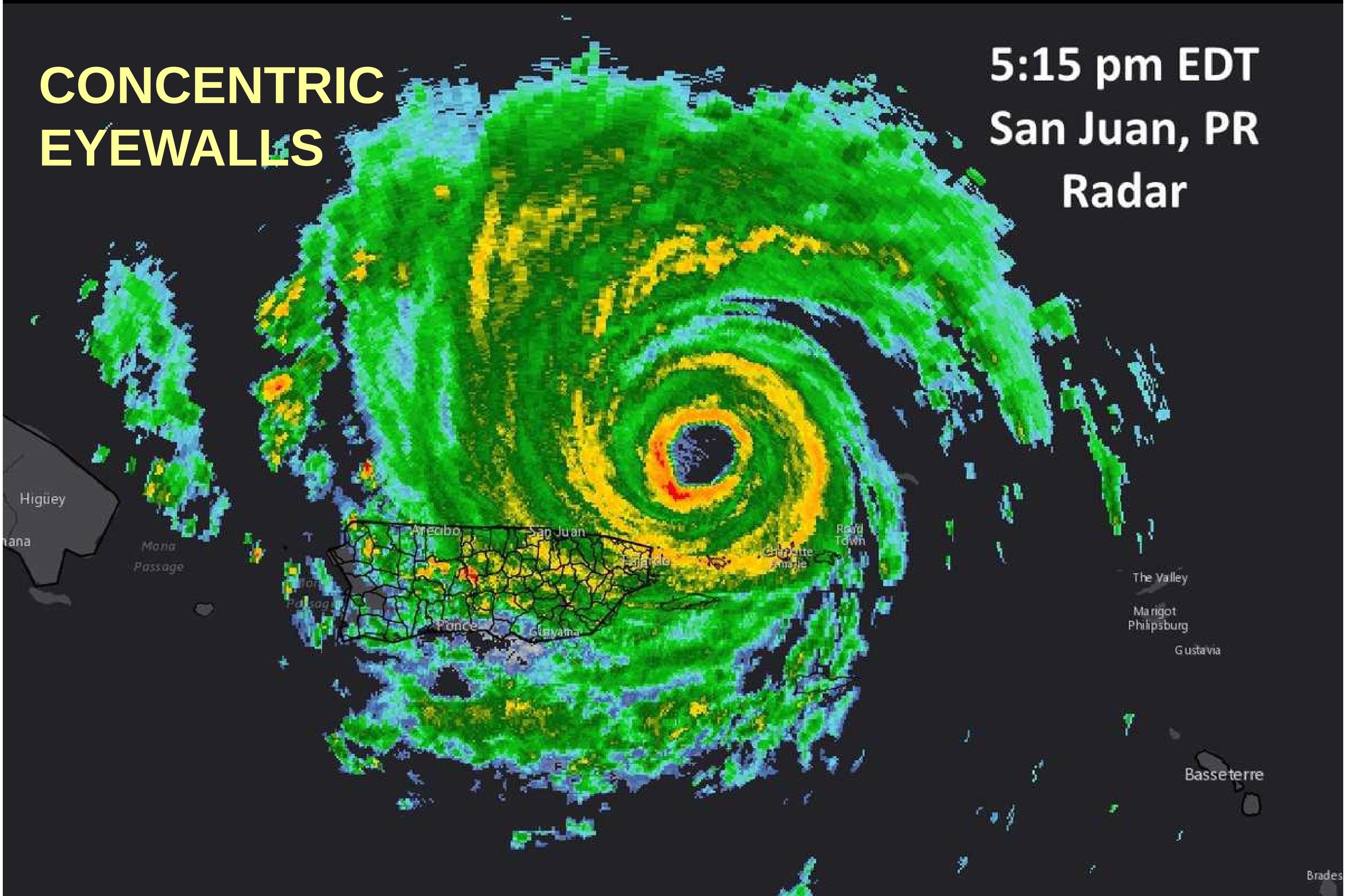
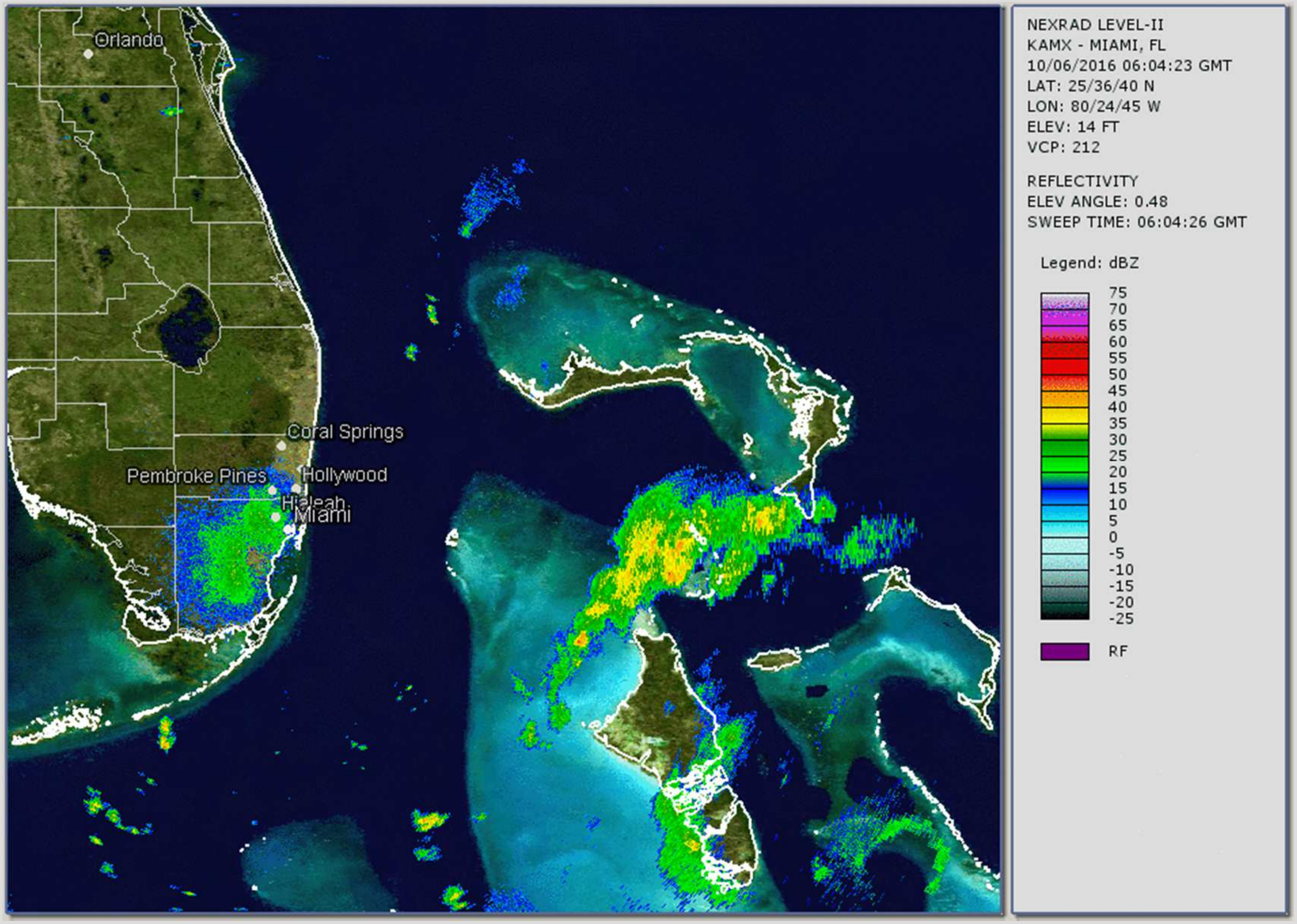
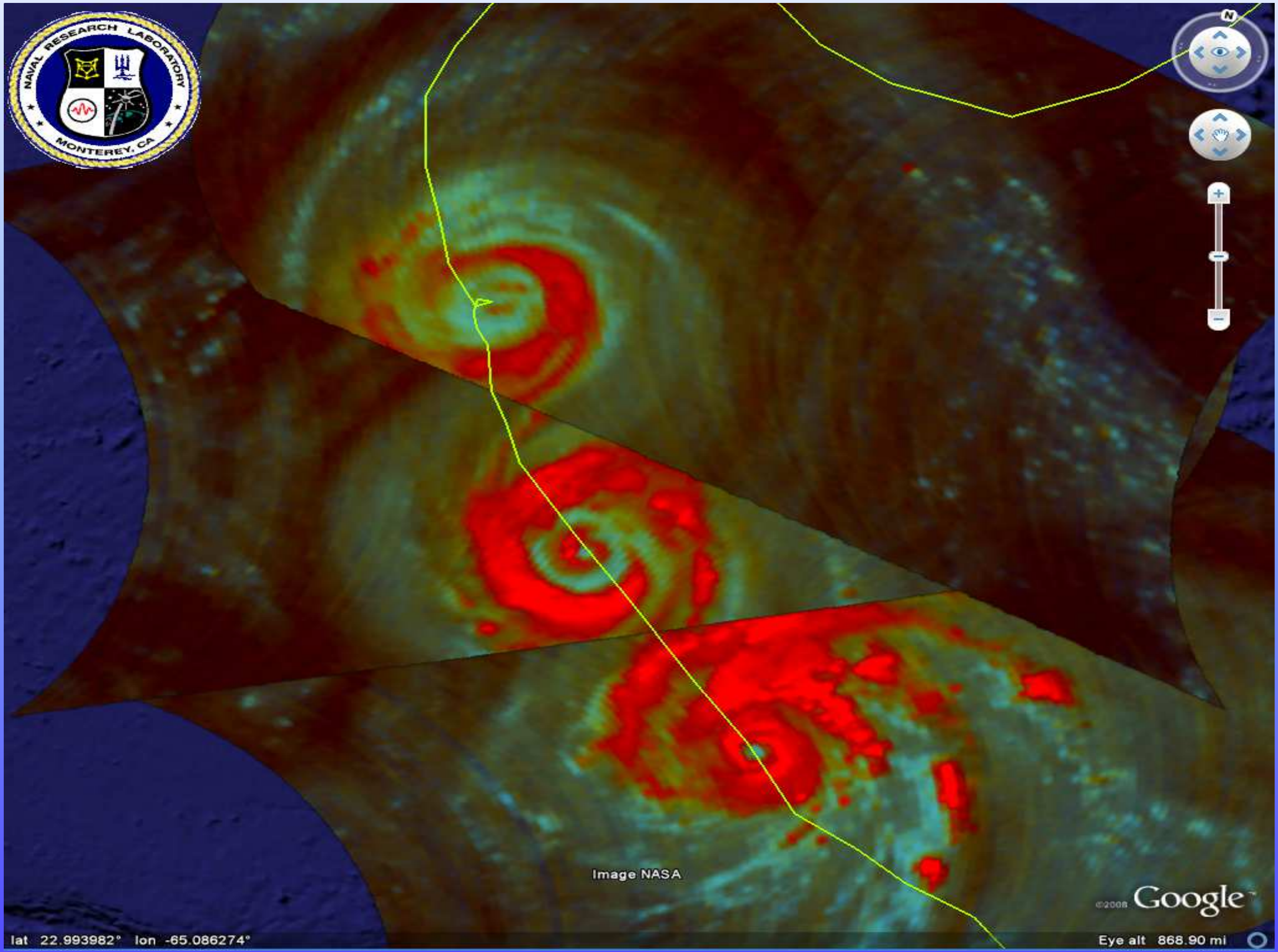
CONCENTRIC EYEWALLS

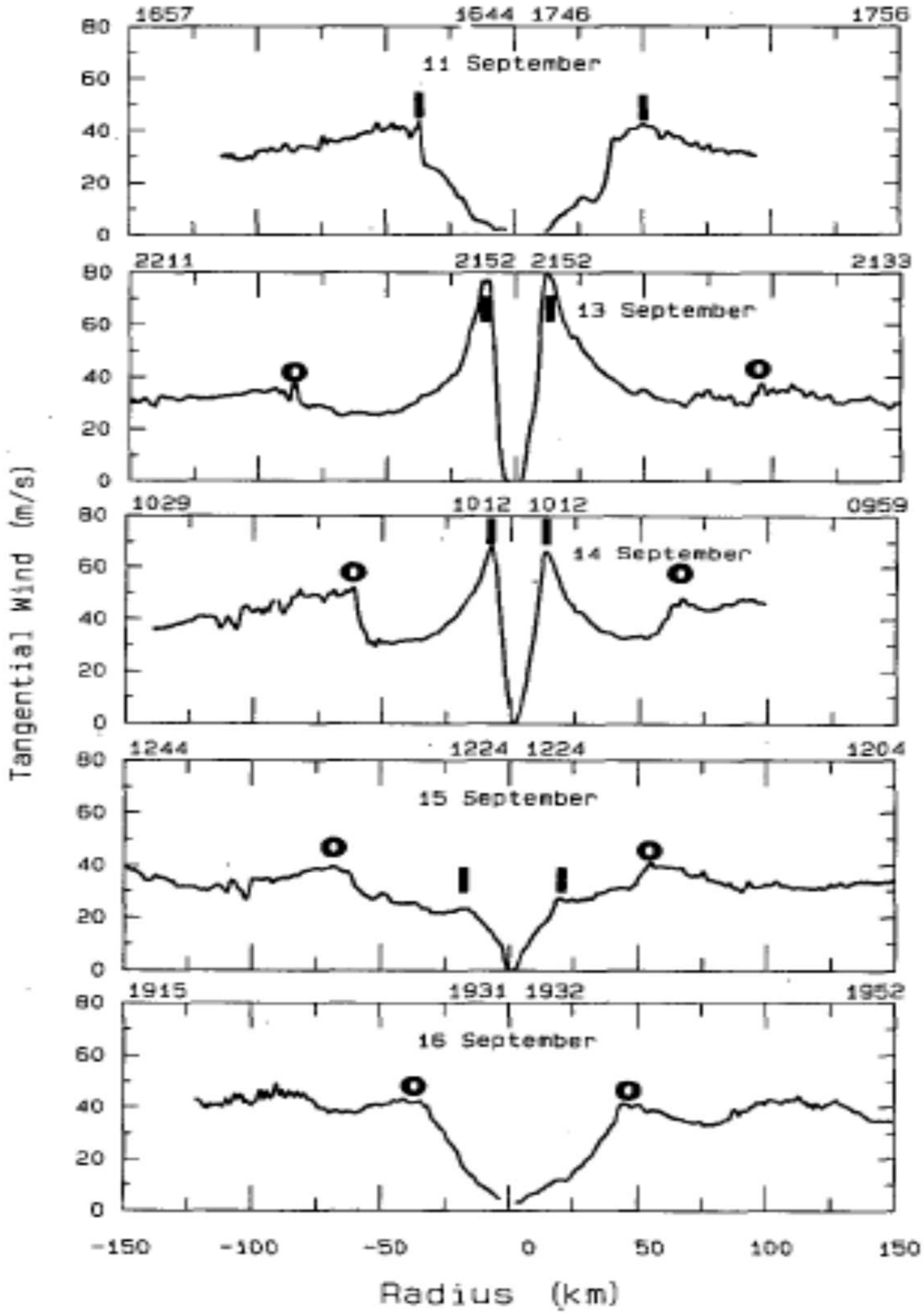


Hurricane Matthew Radar Loop



Bertha (2008) Eyewall Replacement





Concentric Eyewall Cycle –

Tangential winds (Gilbert)

Black & Willoughby (1992)

CENTRAL PRESSURE VS. TIME FOR HURRICANE ALLEN, 1980: LARGE FLUCTUATIONS LARGELY DUE TO EYEWALL REPLACEMENT CYCLES

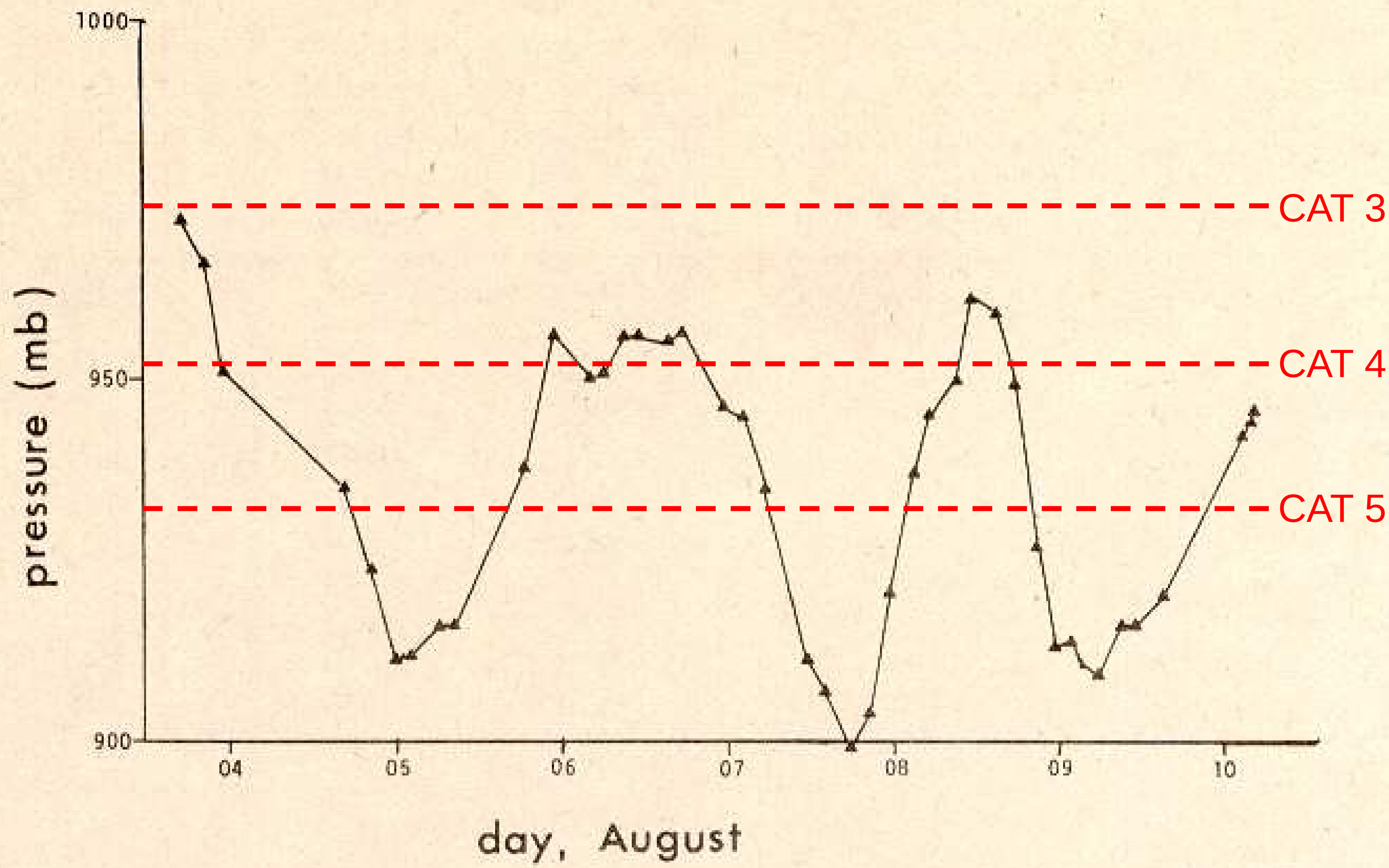


FIG. 3. Hurricane Allen: graph of minimum sea level pressure as a function of time, based on 44 aircraft observations.

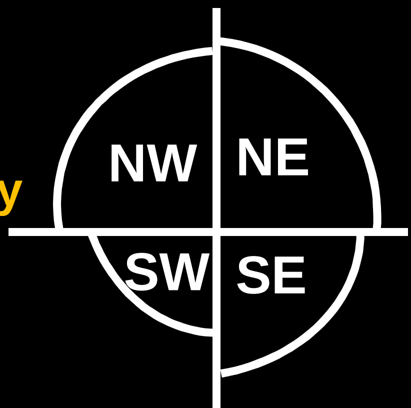
What I know about eyewall replacement cycles

- We have a sense of when they could occur
- We can observe them
- Intensity changes are coming
- Big errors are likely going to happen too…

Tropical Cyclone Wind Radii

NHC estimates cyclone “size” via wind radii in four quadrants

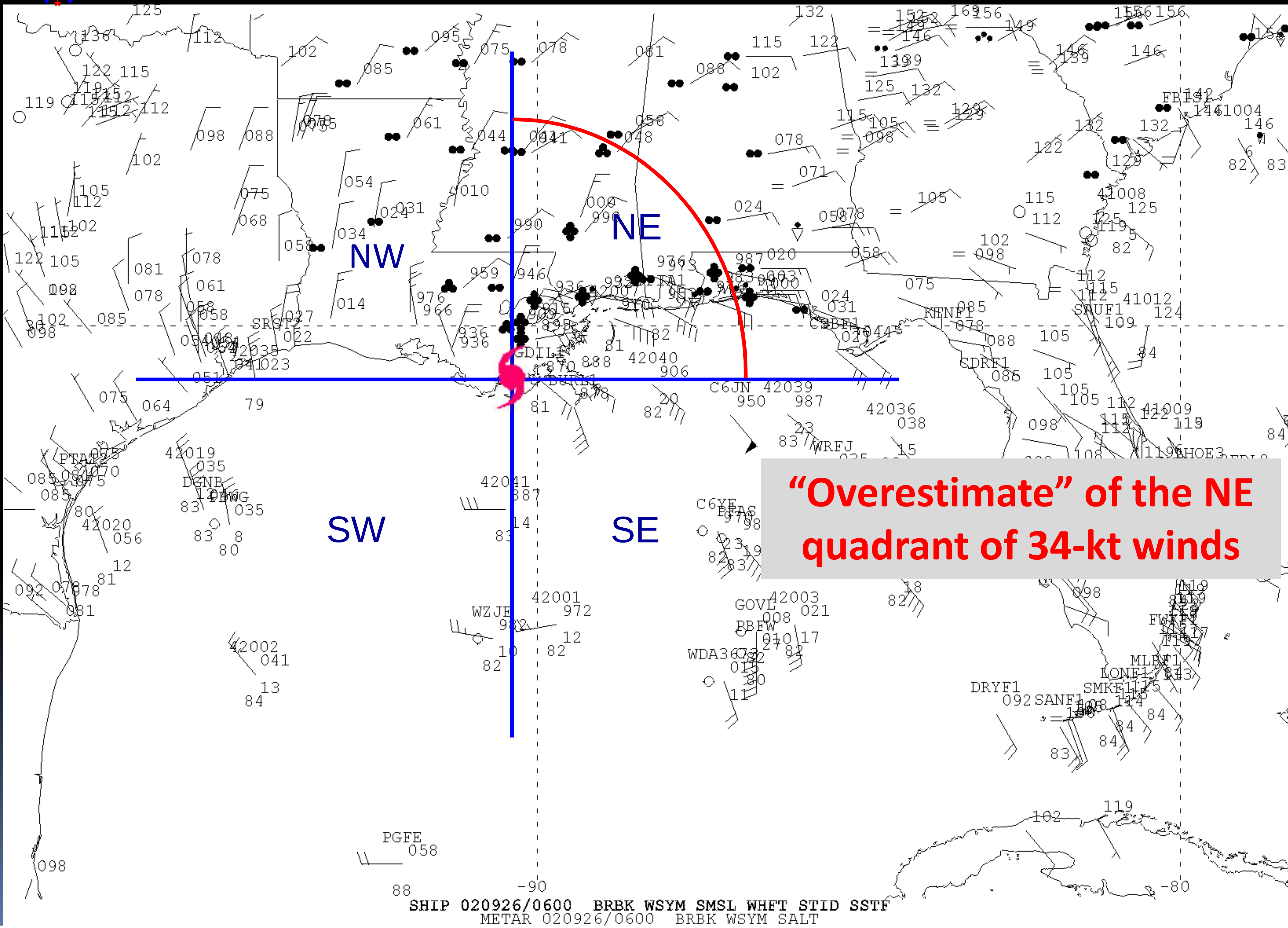
leads to an inherent over-estimate of radii, especially near land



radii represent the largest distance from center in particular quadrant

Wind radius = Largest distance from the center of the tropical cyclone of a particular sustained surface wind speed threshold (e.g., 34, 50, 64 kt) somewhere in a particular quadrant (NE, SE, SW, NW) surrounding the center and associated with the circulation at a given point in time

Limitations of Four-Quadrant Radii



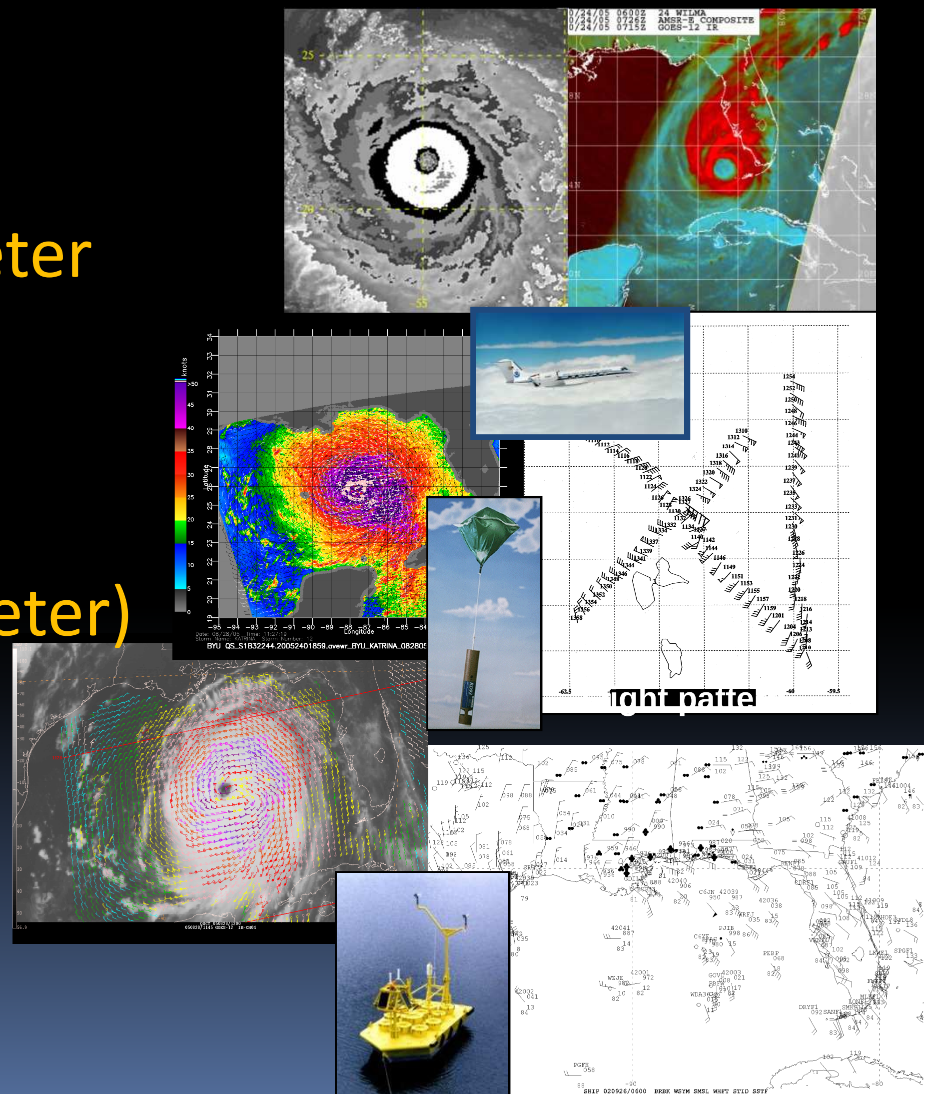
"Overestimate" of the NE quadrant of 34-kt winds

Data to Determine Tropical Cyclone Size

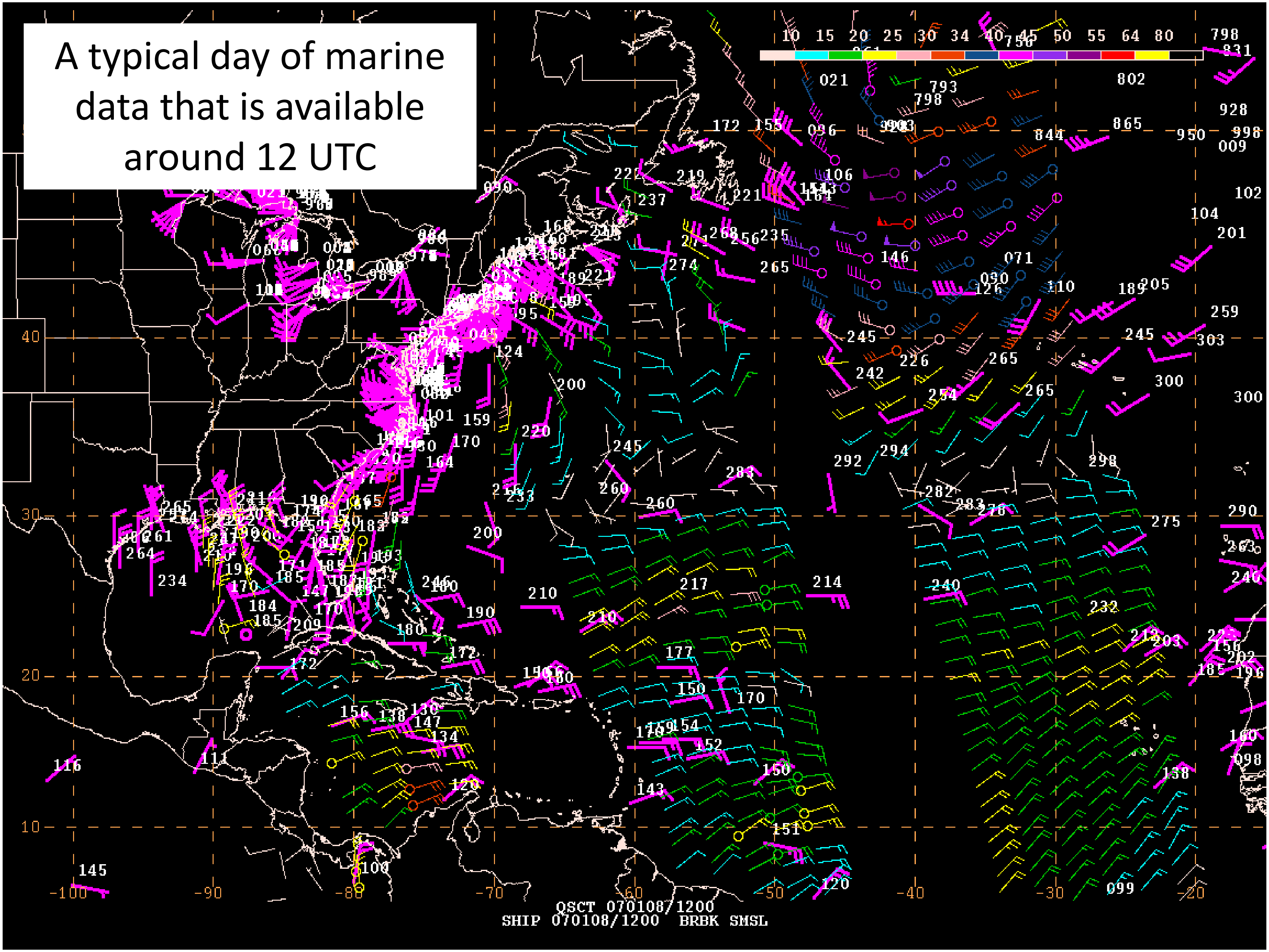
* Satellite Imagery
- Geostationary
- Polar Orbiting – scatterometer

* Reconnaissance Data
- Dropsondes
- SFMR (Stepped Frequency Microwave Radiometer)

* Surface Observations

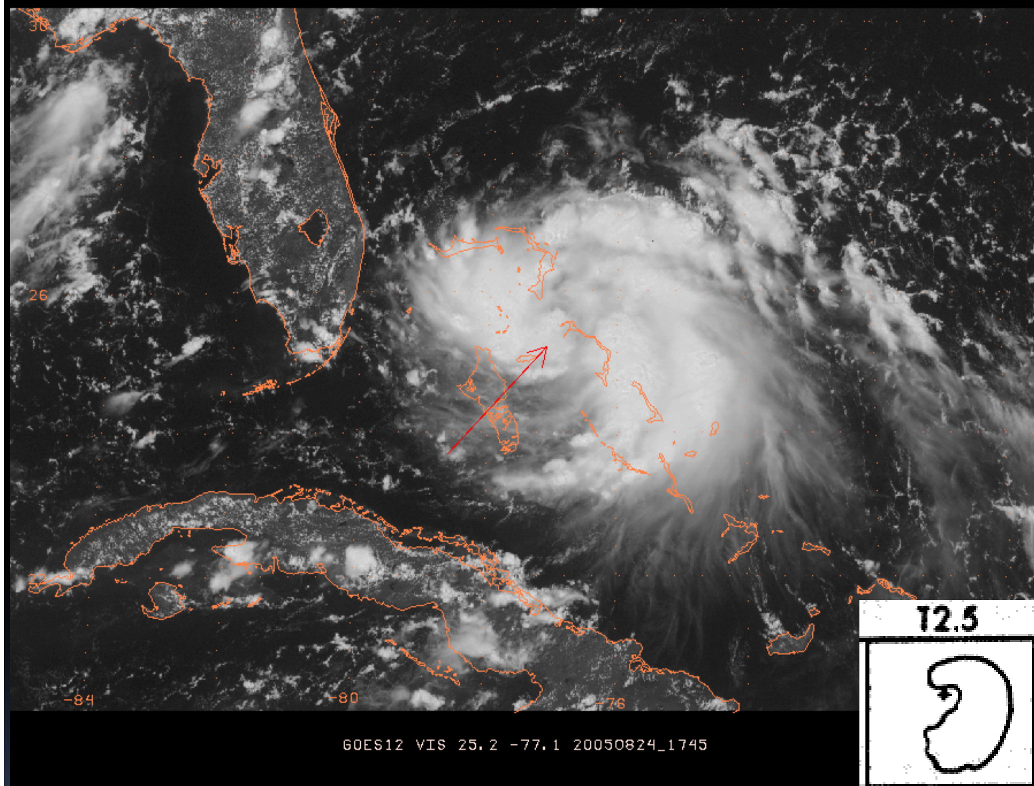


A typical day of marine data that is available around 12 UTC

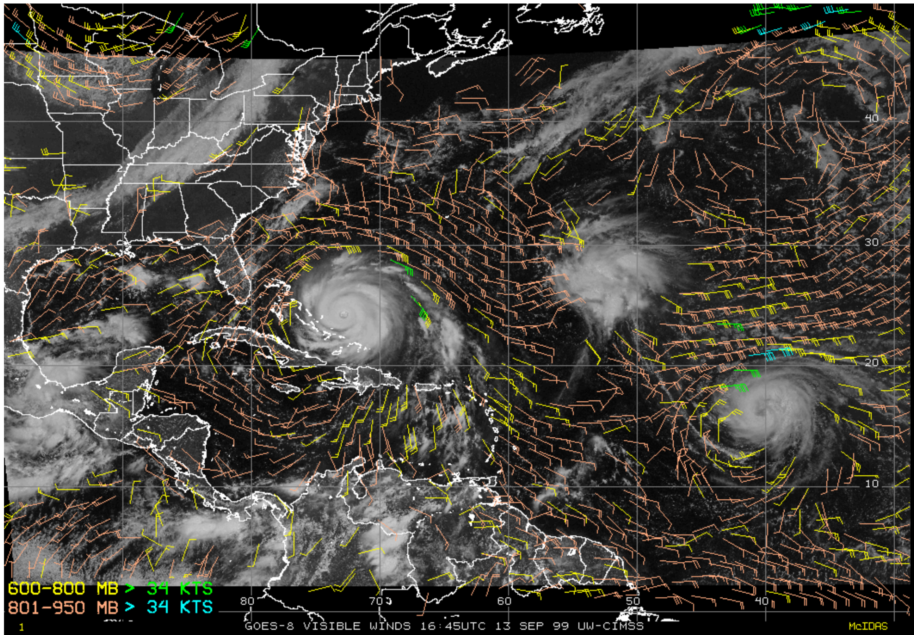


Analyzing and Forecasting TC Size

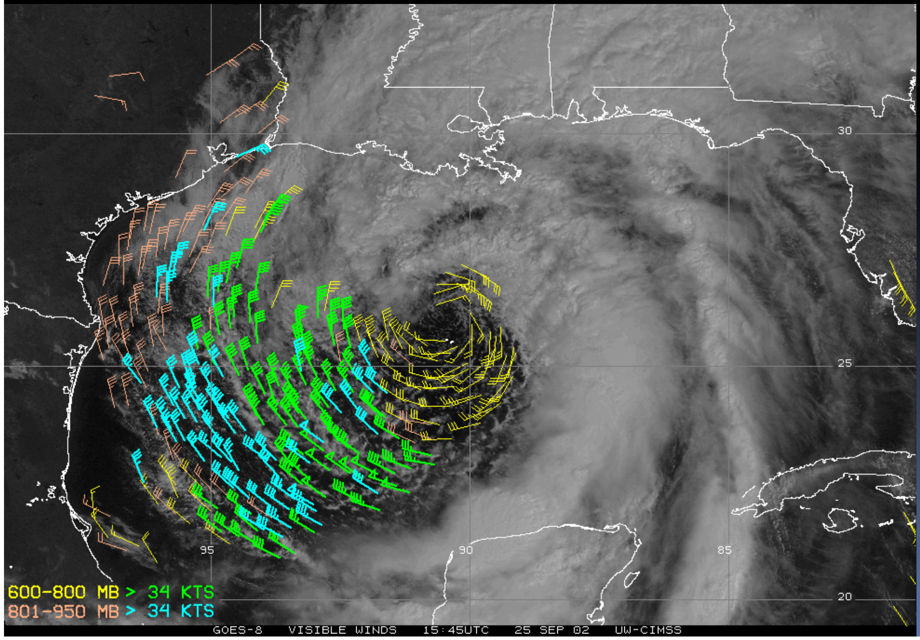
Katrina - August 24



The Dvorak Technique is very skillful at estimating intensity, but does not help with TC size



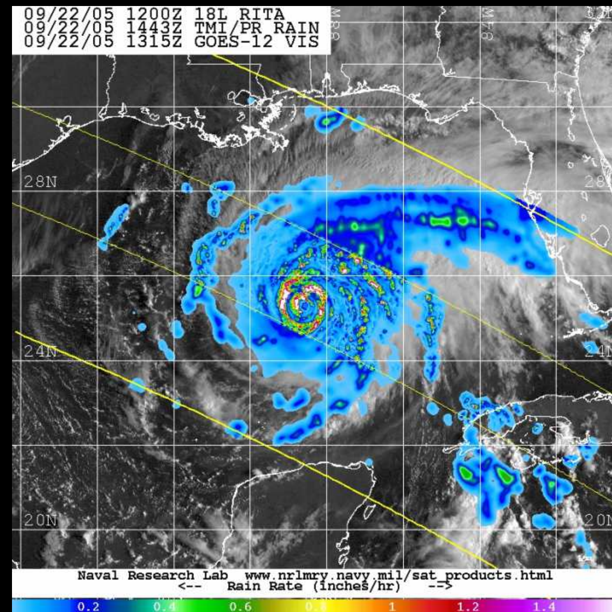
Satellite winds for nearby environment and TC size

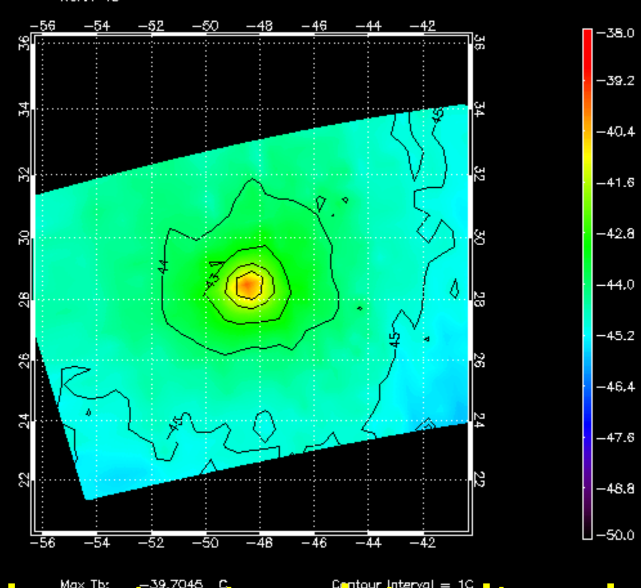


Geostationary satellite – Low-level cloud drift winds

Low-Earth-Orbit Satellites

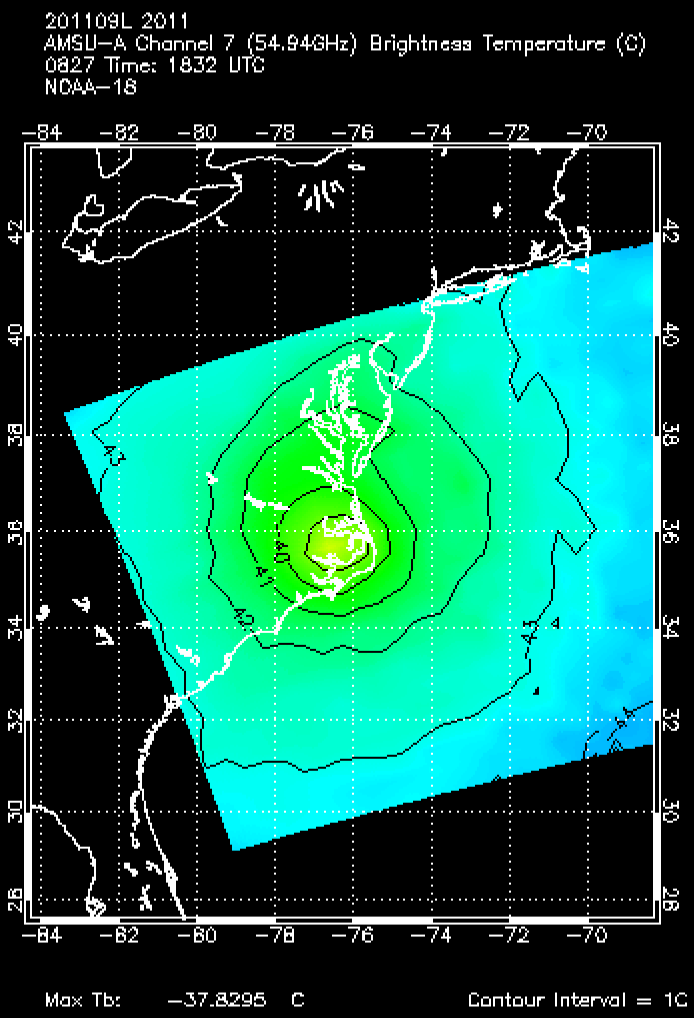
- Carry microwave imagers and sounders that can see through cloud tops and reveal the structures underneath
- Gaps in instrument coverage between orbits, which causes irregular sampling of cyclones

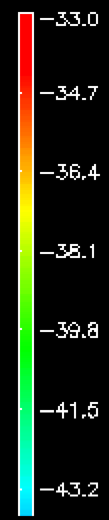


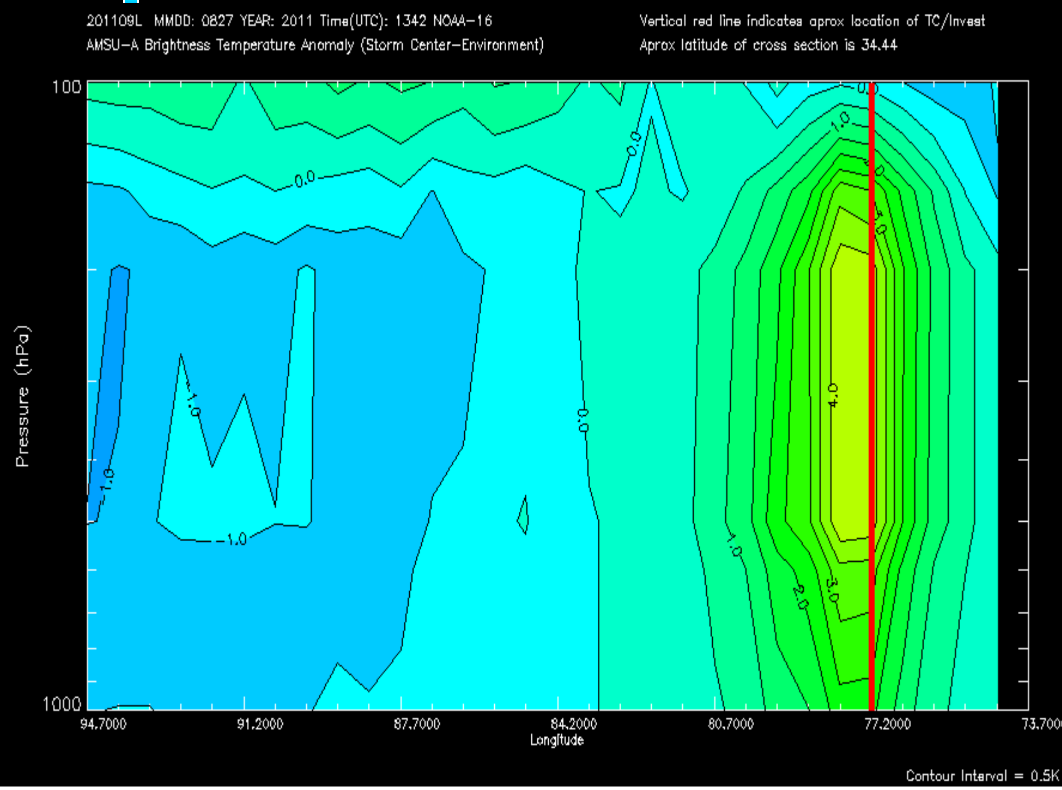


Microwave location, structure, intensity, rainfall

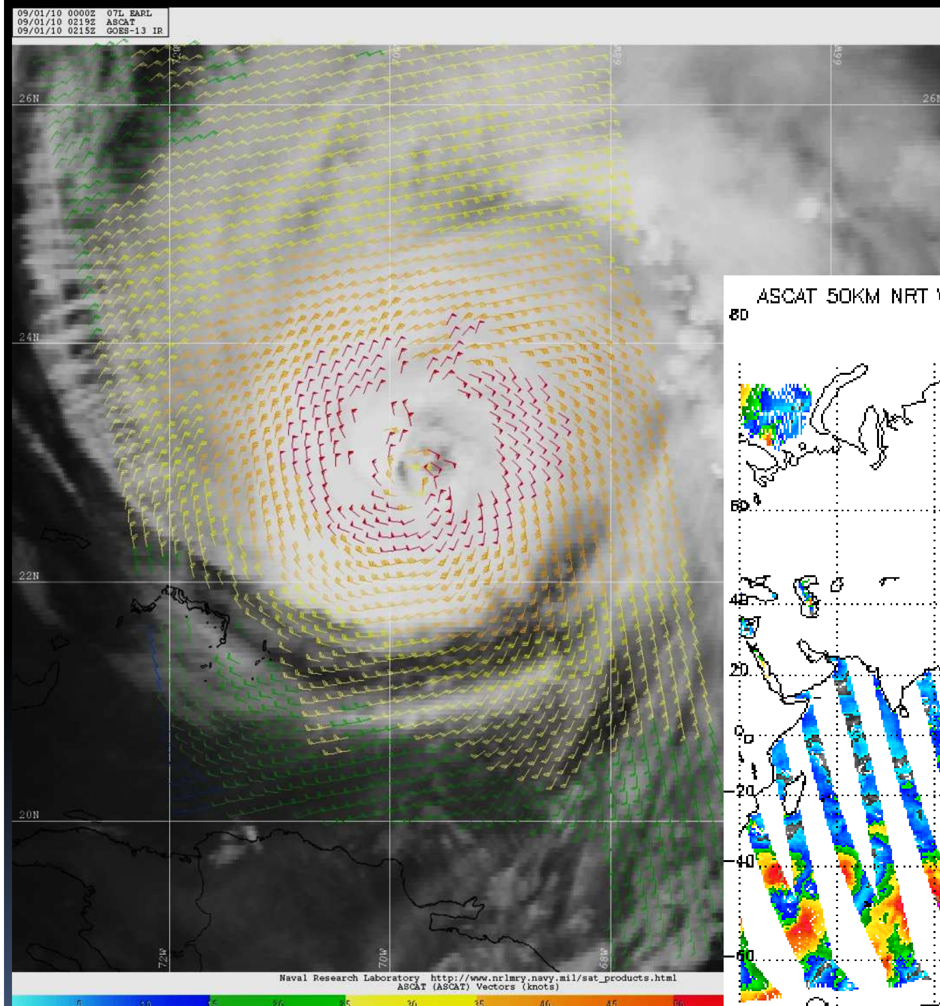
Advanced Microwave Sounding Unit

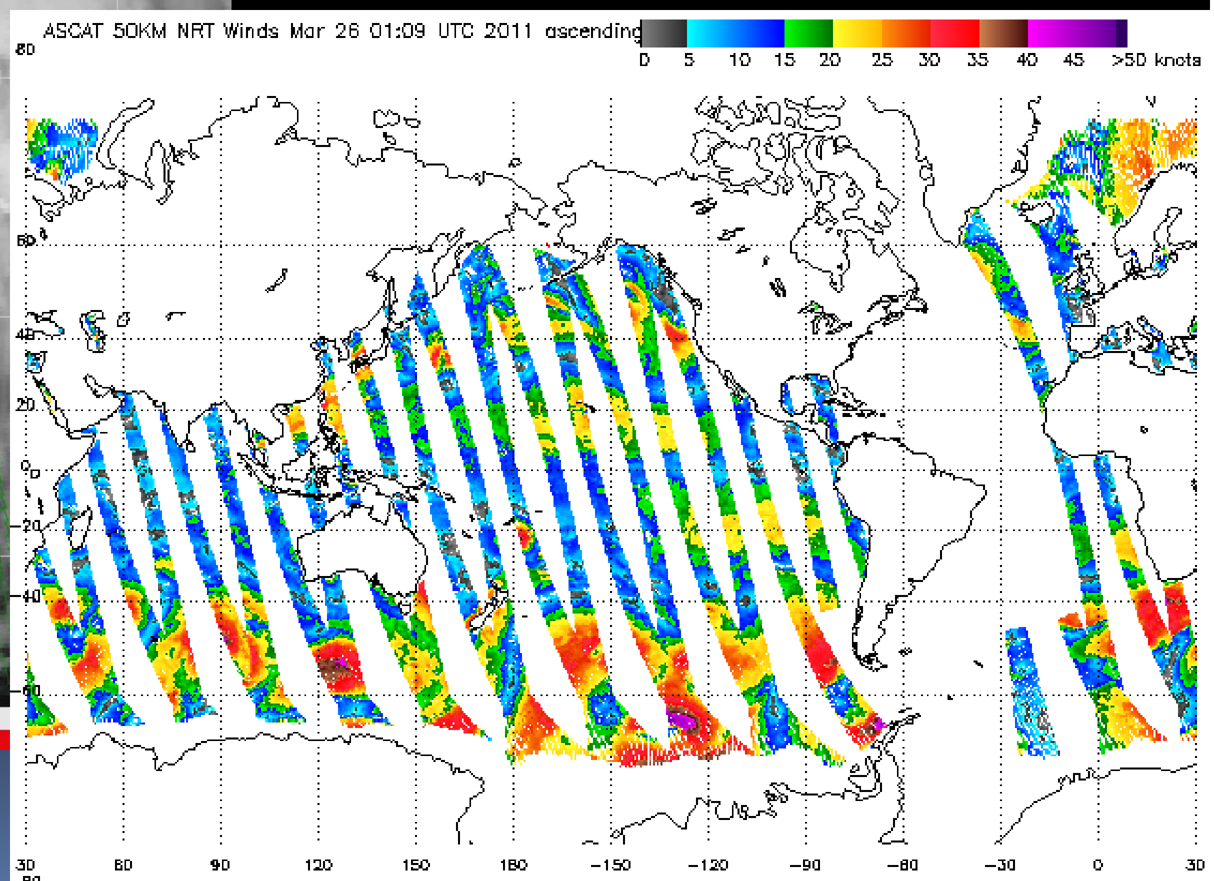






ASCAT (Advanced Scatterometer) – Surface Winds from a Polar-orbiting satellite

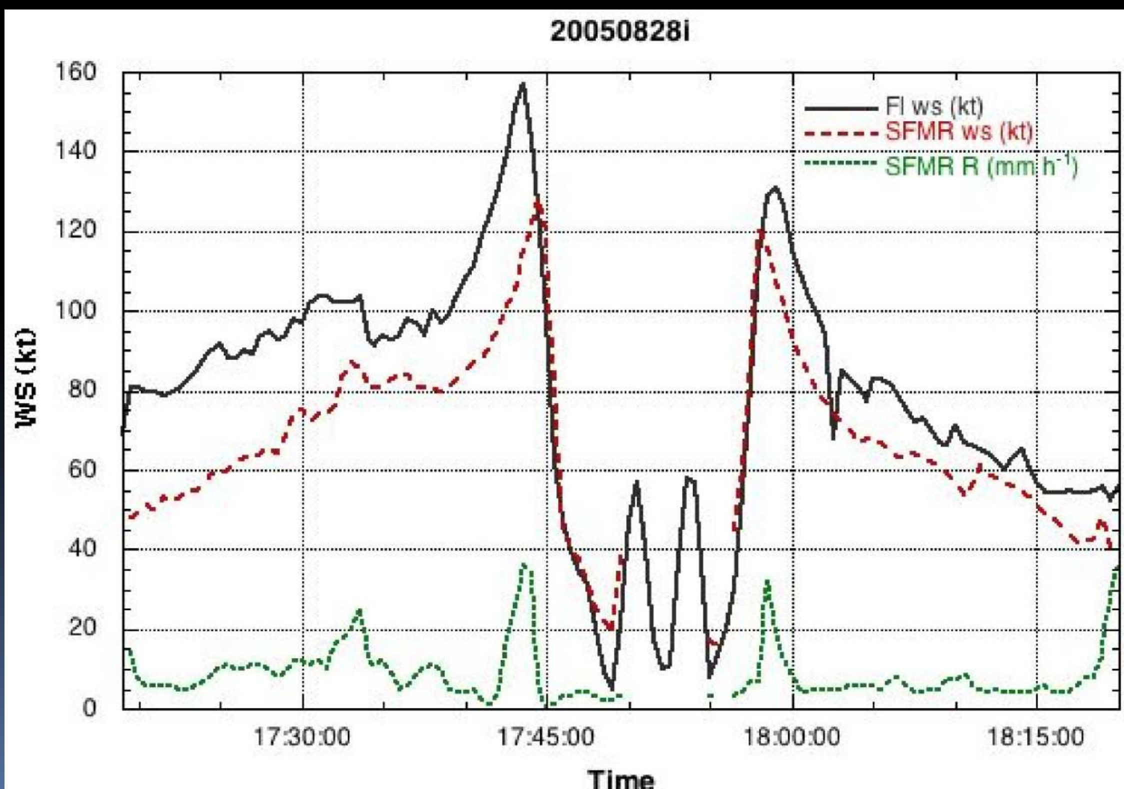


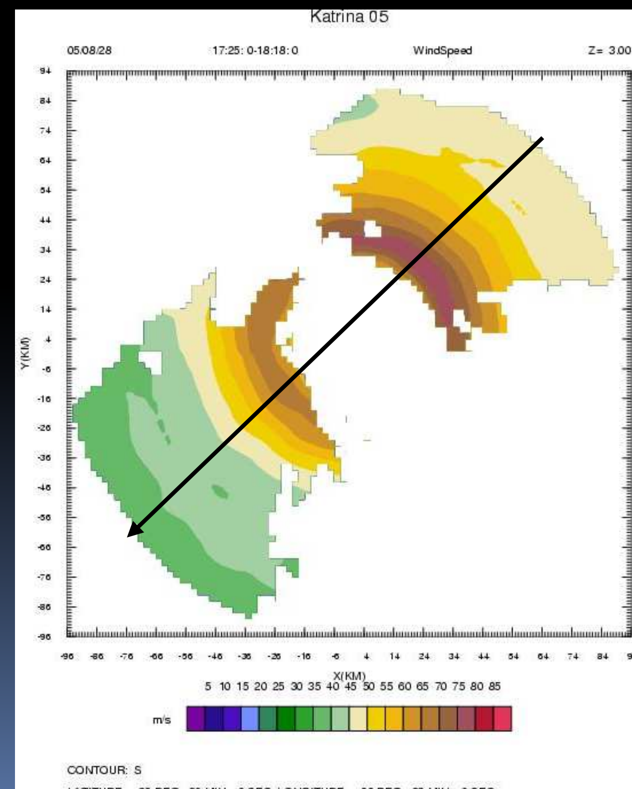


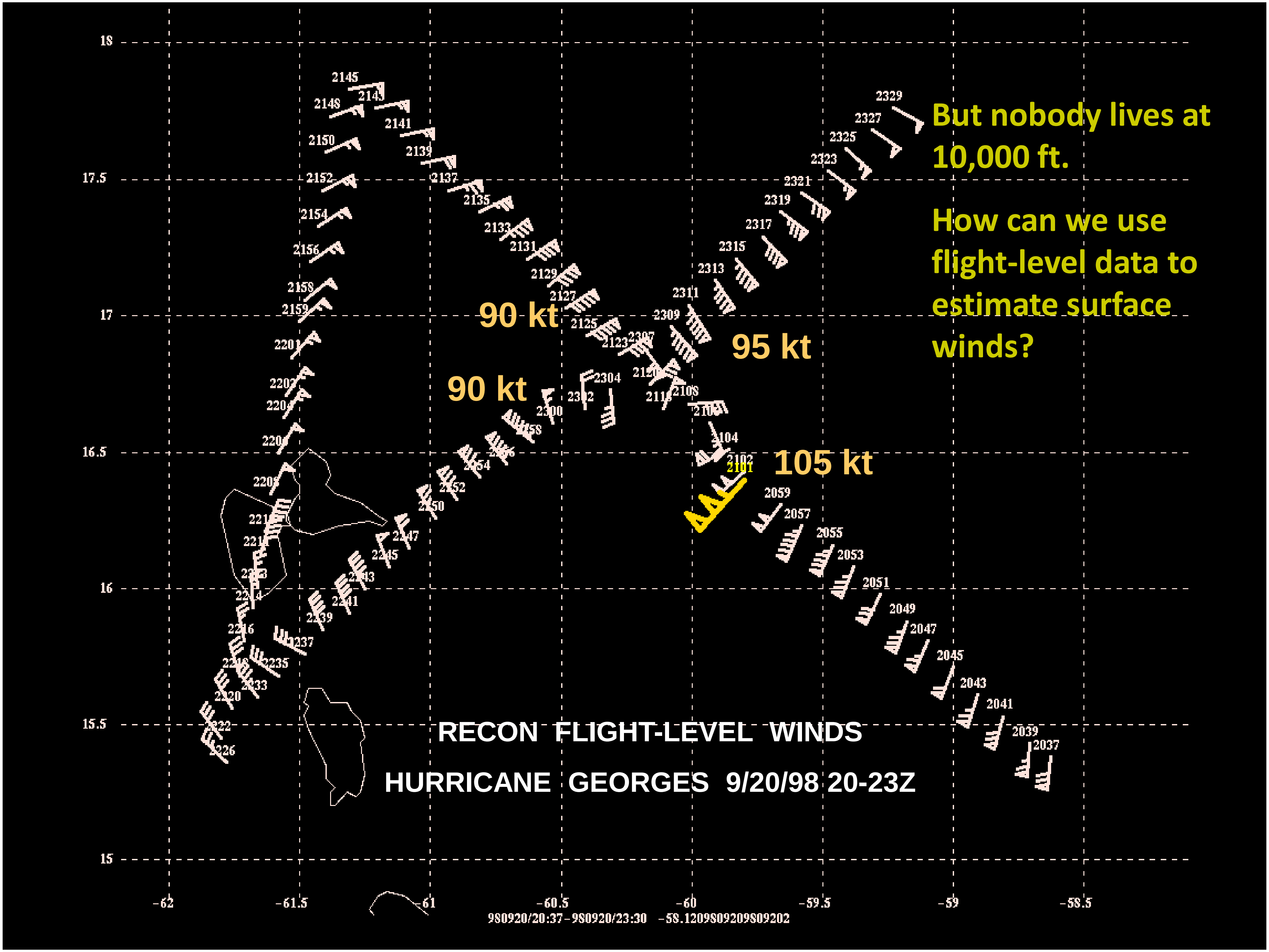
Hurricane Reconnaissance and Surveillance Aircraft (10 Air Force C-130s, 2 NOAA P3s, 1 NOAA G-IV)

Primary Aircraft Data

- Winds (along the aircraft track and dropsondes)
- Surface pressures (extrapolated and dropsonde)
- Surface winds from the Stepped Frequency Microwave Radiometer
- Aircraft Doppler Radar winds (from the P-3's)





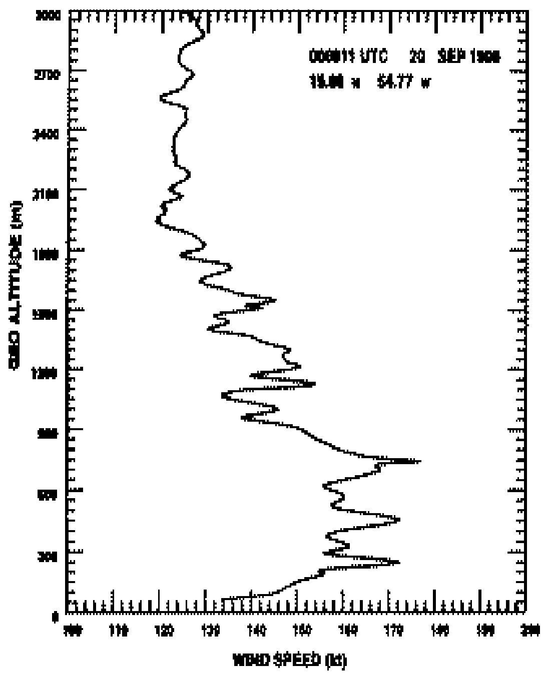


But nobody lives at 10,000 ft.
How can we use flight-level data to estimate surface winds?
90 kt
90 kt
95 kt
105 kt
RECON FLIGHT-LEVEL WINDS
HURRICANE GEORGES 9/20/98 20-23Z
18
17.5
17
16.5
16
15.5
15
-62
-61.5
-61
-60.5
-60
-59.5
-59
-58.5
980920/20:37-980920/23:30 -58.1209809209809202

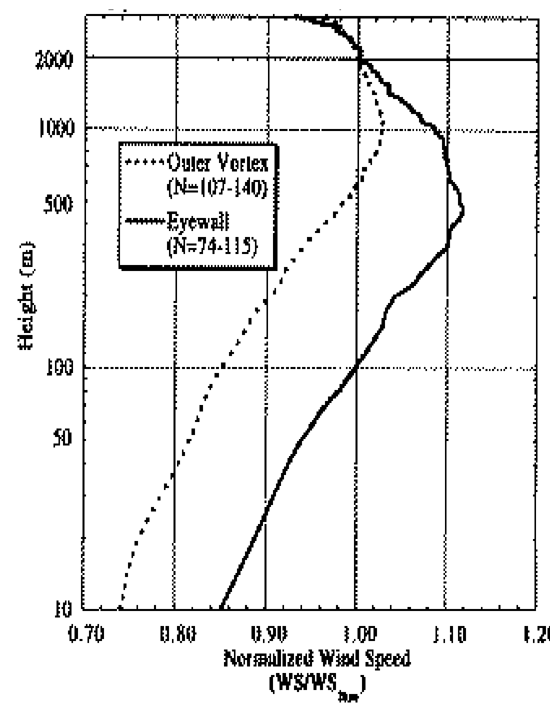
GPS Dropsondes

Measures the wind around and in hurricanes from the aircraft to the ocean's surface

Wind in Hurricane Georges



Mean Wind Profile



Franklin and Black (1999)

Surface wind analyses using flight level winds

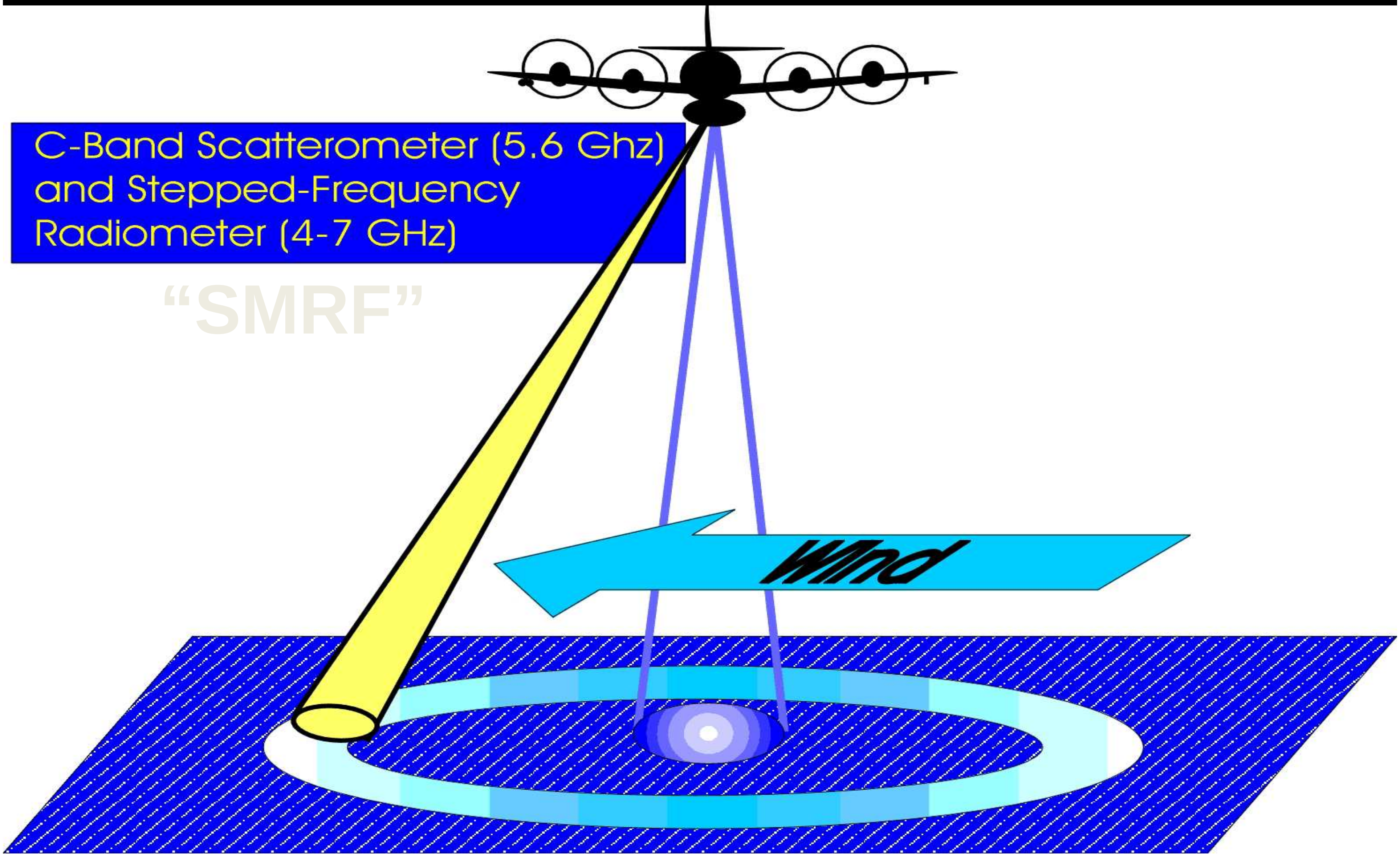
Table 2. Reduction factors and flight-level wind thresholds for determining wind radii from 700 mb data.

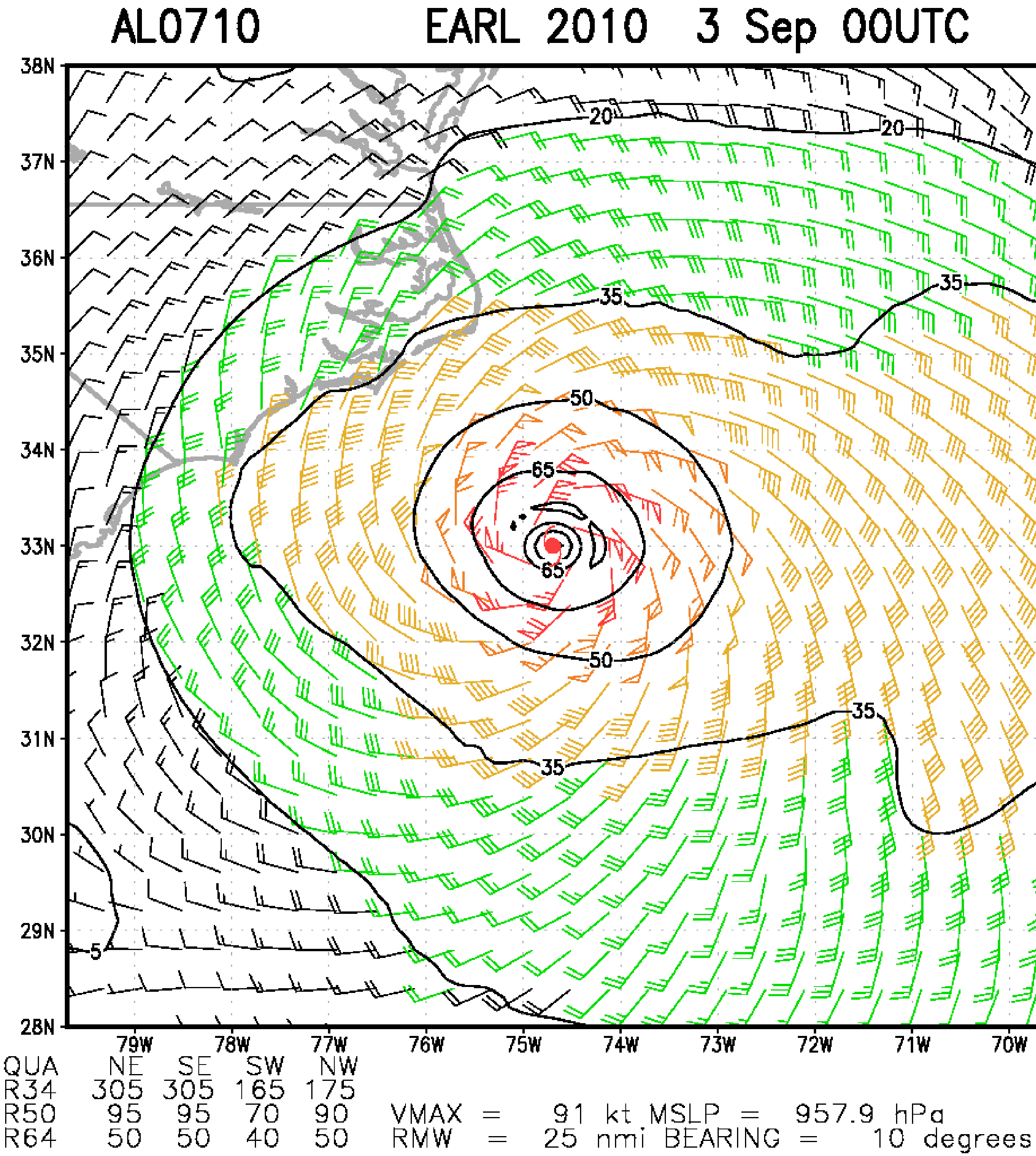
Sample	RF10m	FLW64 (kt)	FLW50 (kt)	FLW34 (kt)
Eyewall	0.90	70	55	-
Outer vortex	0.85	75	60	40
Outer vortex / Right quad	0.75	85	65	45
Outer vortex / Left quad	0.90	70	55	40

A large sample of GPS dropsondes in the inner core of TCs provides a way to determine surface wind radii from flight level winds via the mean wind profile

Franklin (2001)

Remotely Sensed Surface Winds





Multiplatform Satellite Surface Wind Analysis – CIRA

Automated Surface Wind Field in Tropical Cyclones

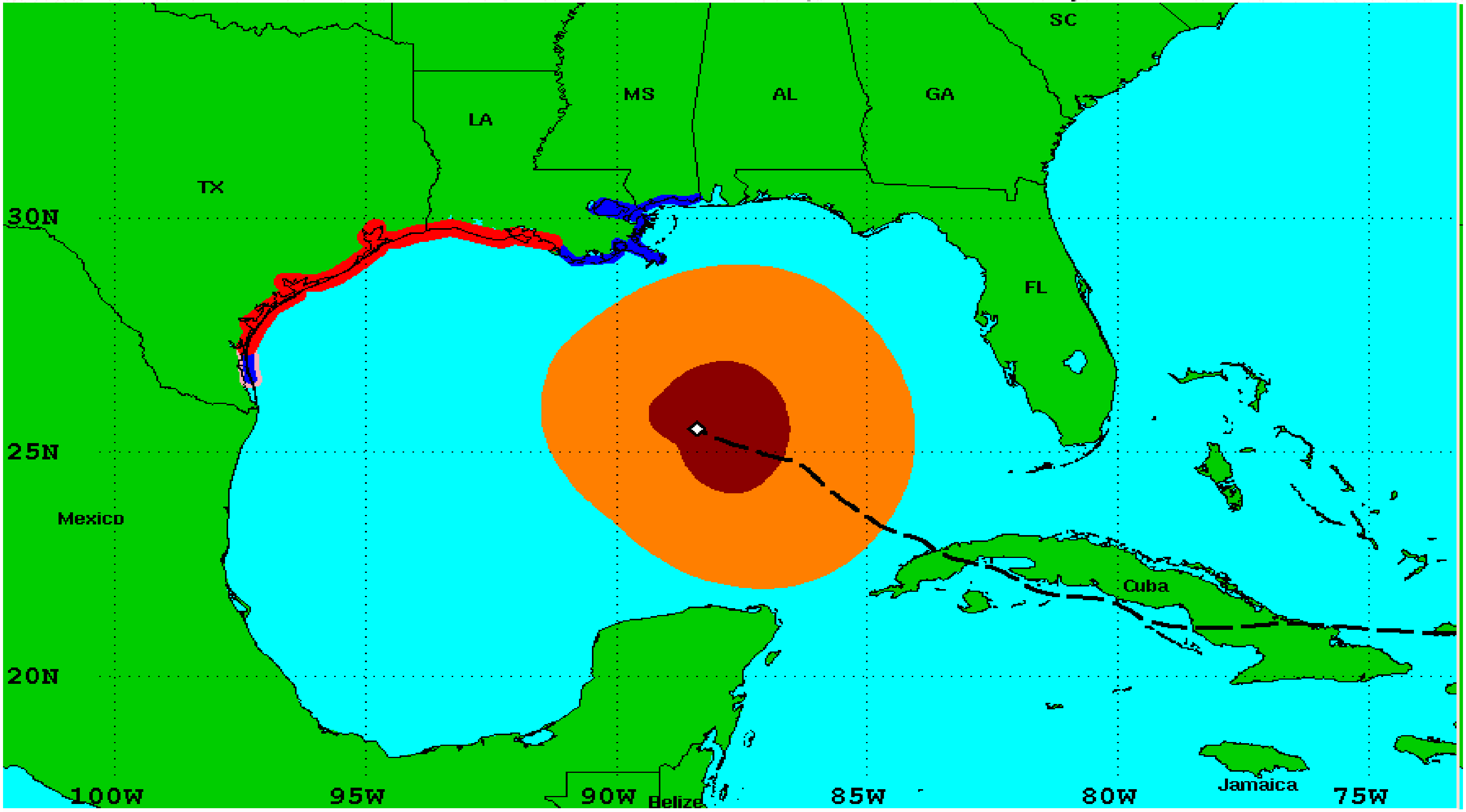
And after using all of that data, we come up with this…

8:12 PM

Surface Wind Field

Surface Wind Field of Hurricane Ike

Sustained Winds as of 1000 AM CDT Thu Sep 11, 2008   Advisory Number 42



Watches:
- Hurricane Watch
- Tropical Storm Watch

Warnings:
- Hurricane Warning
- Tropical Storm Warning

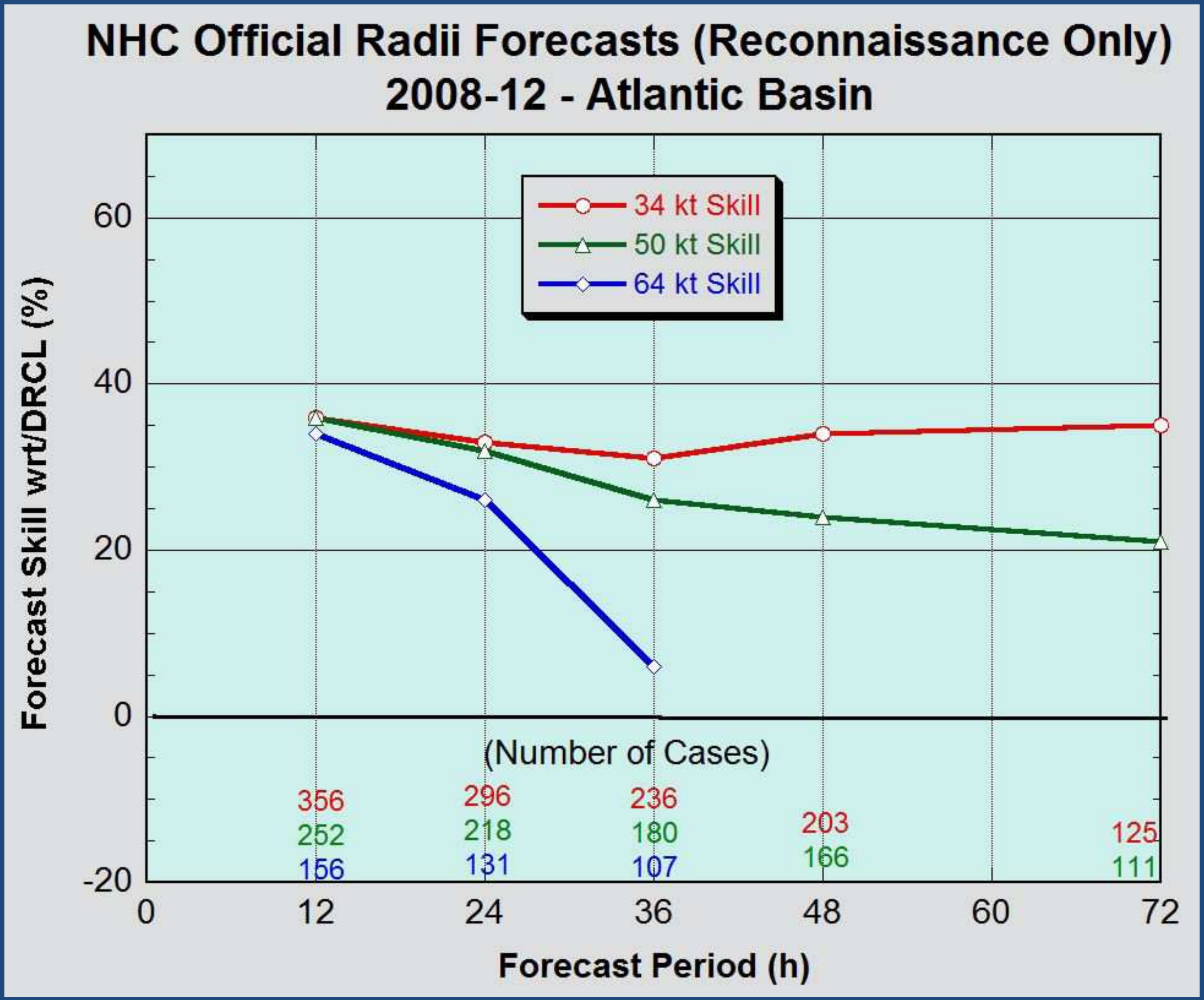
Sustained Winds:
- Hurricane Force
- Tropical Storm Force

Position:
- Center as of 1000 AM CDT
- Past Track

Wind Radii Forecast “Guidance”

- Empirical ideas
  - Is the storm strengthening or weakening?
  - Is persistence appropriate, or are conditions changing?
  - Is the storm becoming extratropical, causing wind field to expand?
  - Will all or part of the circulation be passing over land, such that radii could decrease?
  - Is the system accelerating, such that the storm could become more asymmetric?

NHC Forecast Skill

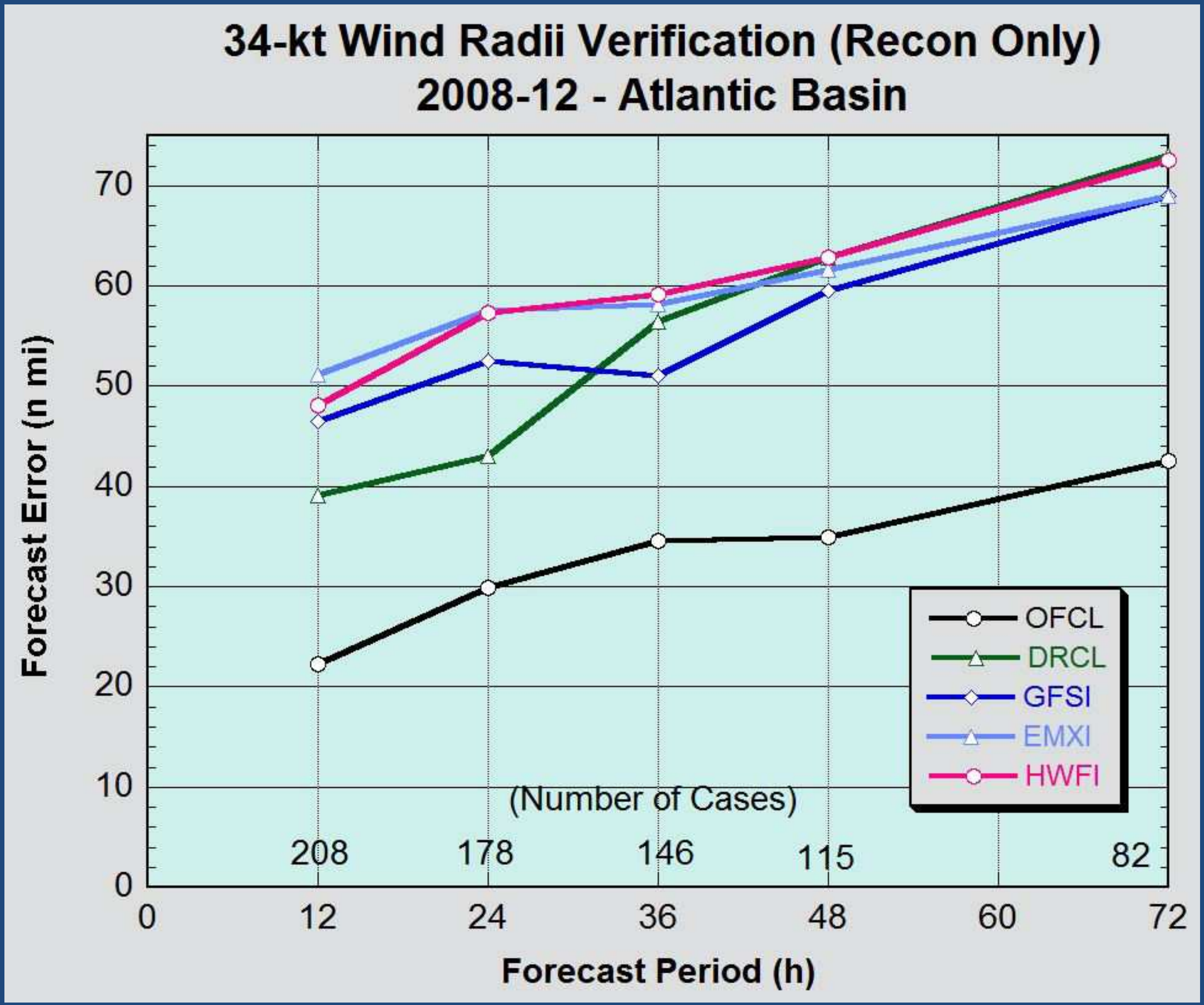


Yes, the NHC wind radii forecasts are skillful. Skill declines over time.

34 kt skill: ranges from 30-35%
50 kt skill: ranges from 20-35%
64 kt skill: ranges from 5-35%

How good is the guidance?

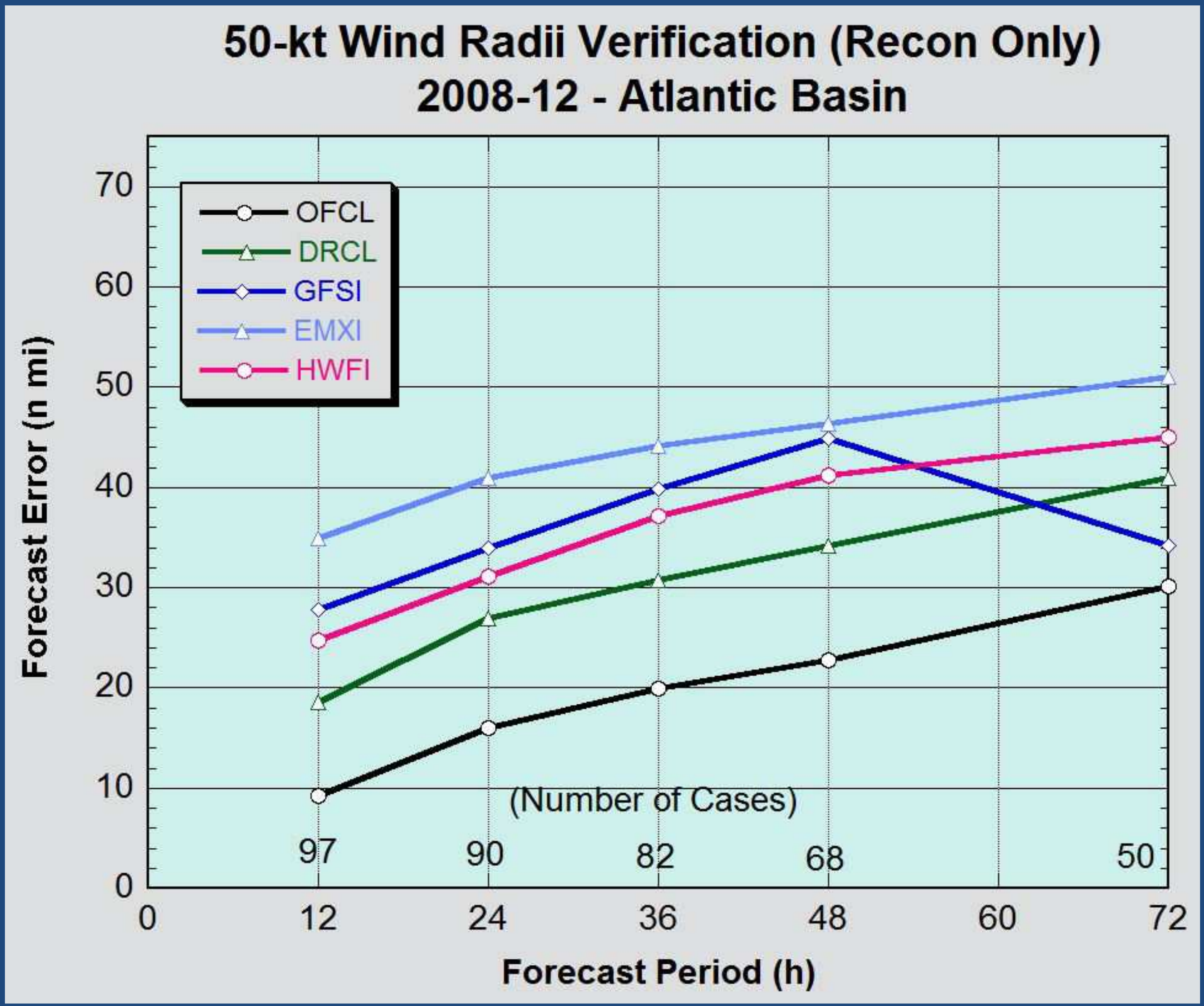
The Models - 34 kt Verification



The guidance is not very good. OFCL is considerably better than all of the dynamical guidance shown here.

GFSI and EMXI have some skill (errors are lower than DRCL)at 48 and 72 h.

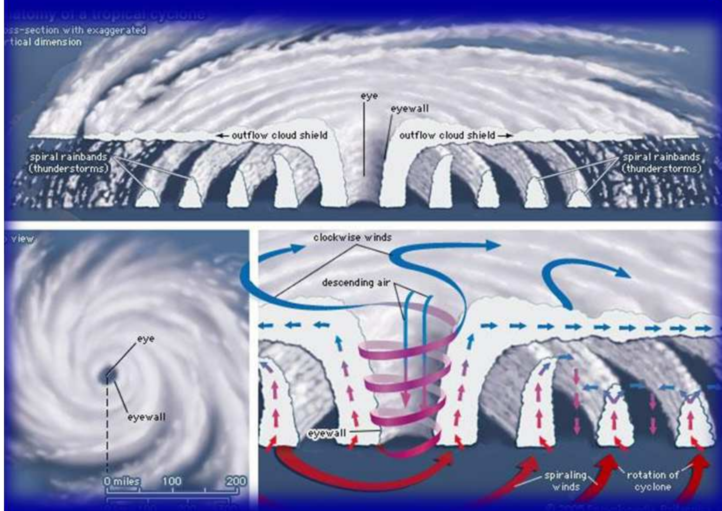
The Models - 50 kt Verification

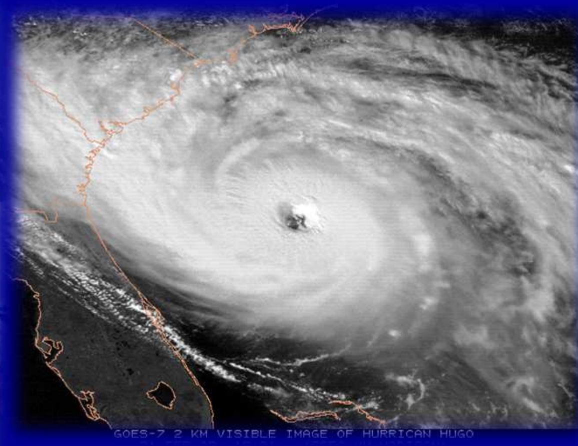


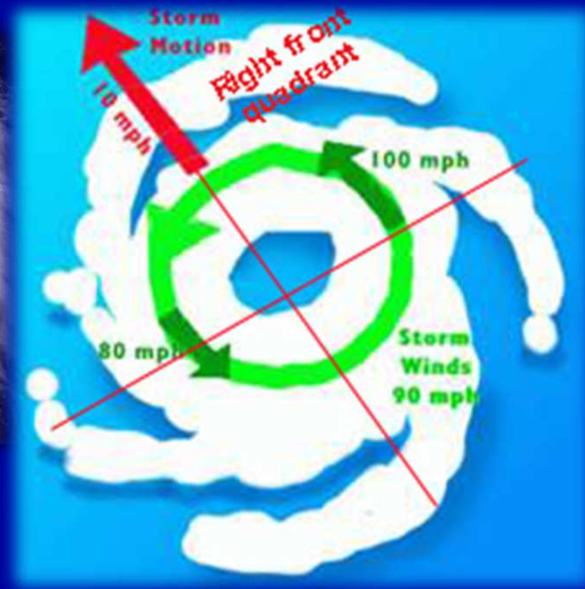
OFCL is considerably better than the dynamical guidance.

Among the guidance, only the GFSI had skill at 72 h.

Hurricane Structure: Theory and Application







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World Meteorological Organization Workshop